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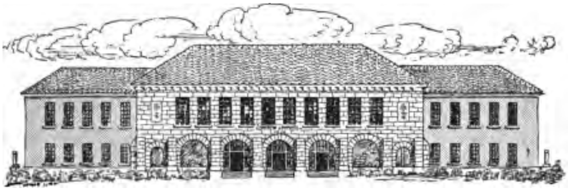

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MANUAL OF
EXPERIMENTAL PHYSICS

FOR SECONDARY SCHOOLS

BY

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PREFACE.

THIS book originated three years ago in the necessity for a thorough revision of the laboratory manual then in use in the Chicago High Schools. About a year ago the undersigned, who up to that time had done most of the work of revision, were requested by the Physics teachers of the city to complete the book and prepare it for publication.

The policy of the Chicago Physics teachers has been for several years to make the laboratory work inductive as far as possible. This book is written from this point of view. The pupil is told very little that he can find out for himself by a reasonable amount of work, in the course of his experiments.

The authors are not so visionary as to suppose that pupils can, unaided, rediscover the laws of Physics, but they know that, if sufficiently careful directions are given to pupils for the performance of experiments, and definite instruction is given them as to the manner of *studying results,* many of nature's great laws will be learned first-hand. And these will be much more strongly impressed than when learned from a text-book or from the teacher's experiments.

The experiments have been carefully selected with a view of developing some principle of Physics as well as of training the intellectual faculties. They are mainly quantitative, though some are qualitative, since qualitative experiments performed by the pupil himself will frequently appeal to him in a way that is absolutely impossible if performed by the teacher. Often a subject forbids quantitative treatment in such elementary work, yet demands a qualitative place. Further, qualitative experiments frequently serve to stimulate the pupil's interest, and therefore deserve consideration.

Much care has been taken to make the directions very full and complete, especially in the earlier part of the work. It is expected that they will require little further explanation.

Unless stated to the contrary, the metric system of measurements is used throughout the course, and all temperatures are given in Centigrade degrees.

The book contains a very complete list of tables, selected from the best American, English, and German authorities, thus making it exceptionally valuable for reference. It is a laboratory manual only, intended to supplement and *not* replace whatever text-book may be in use.

Equivalents are given for every one of the exercises required for admission to Harvard University, as given in the Harvard pamphlet, with the exception of Nos. 11, 35–38, 41, 47, 53, and 61. It also conforms to the ideas and suggestions of the Committee of Ten. It contains much more material than is required for admission to any college. It is not expected that each pupil will perform all of the experiments. An opportunity is given to each instructor to select such experiments as time and circumstances permit.

All but two of the cuts were made especially for this book. Nearly all the drawings for these cuts were made by Frank N. Ropp and George G. Schneider, pupils in the Chicago English High and Manual Training School. A few of the cuts were kindly loaned by the Chicago Laboratory Supply and Scale Co.

Material has been selected from all available sources, but the treatment has been entirely independent.

The manuscript was read and criticised by Professor Carhart of the University of Michigan, Professor Carman of the

University of Illinois, Professor Carman of Lewis Institute, Professor Crew of Northwestern University, and by the Department of Physics of the University of Chicago, to whom thanks are hereby extended. Especial acknowledgment of obligation is due to Professor Crew for criticisms and helpful suggestions.

The authors alone are responsible for any errors which may appear.

A list of apparatus and supplies required for this course will be found on p. 315 of the Appendix.[1]

FRED R. NICHOLS.
CHICAGO, July 1, 1901. CHAS. H. SMITH.
CHAS. M. TURTON.

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[1] The apparatus referred to above can be obtained of the following firms: The Chicago Laboratory Supply and Scale Co., 39 W. Randolph St., Chicago; Richards & Co., Ltd., 108 Lake St., Chicago; L. E. Knott Apparatus Co., 14 Ashburton Place, Boston; Ziegler Electric Co., 141 Franklin St., Boston.

The Chicago Laboratory Supply and Scale Co. make from designs furnished by Chicago Physics teachers various forms of apparatus, among which are the very desirable pieces shown in Figs. 17, 18, 36, and 103. The balances shown in Figs. 17 and 36 are due to Mr. C. E. Linebarger of the Lake View High School. The D'Arsonval Galvanometer shown in Fig. 103 is due to Mr. Charles H. Smith of the Hyde Park High School. The Torsion Apparatus of Fig. 18 is a modification of that in use at the Lewis Institute, Chicago.

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INTRODUCTION.

GENERAL.

In nearly all schools the time allotted to the subject of physics is altogether too short. This being the case, it becomes necessary for the pupil to do as much of the work as possible outside the laboratory. It follows of course that the laboratory time is exceedingly valuable. The pupil then should strive to economize that time as far as possible. Much time will be saved if computations as in Exp. 1, *f*, are done at home. There should be at least six hours of school time devoted to physics weekly, and this should demand eight hours or more of outside work for preparation, computations, problems to be handed in, study of results, etc. The pupil should do at home as many of the text-book experiments as possible.

The apparatus need not be expensive. Many of the more important pieces may be "home made," according to the directions in the Appendix.

About one-half the physics time should be devoted to experimental work in the laboratory; the other half to recitations, lectures, discussion of finished experiments, etc.

Much time is usually required in getting apparatus together and in working order. The laboratory period should be long, in order that the work may be finished when once begun, and thus require this preliminary work to be done but once.

Every piece of apparatus in the laboratory should be numbered or designated in some manner, so that the particular piece used in any work may be noted and readily located again if necessary.

Pupils should not be allowed to consult a text-book during the process of an experiment, though there should be a good library for consultation both before and after the experimental part is finished.

In the earlier experiments the directions should be followed exactly as given; with experience the pupil will learn to discriminate between the directions which must be followed absolutely, and those which admit of modification to suit circumstances.

In the writing of notes the pupil has an opportunity for much self-improvement in the use of English. Although the teacher of physics is usually hard pressed for time, he can ill afford to accept anything other than the best effort of the pupil in this respect.

It is sometimes desirable to protect the clothing by an apron and sleeves. Of all material for such use, rubber is by far the best. Such protection is absolutely necessary in chemistry, and if provided for physics may be used for both.

For a burn apply a paste of ordinary baking soda (saleratus) mixed with water. It must be kept moist. It may well be bound in place with a cloth.

A fire can best be extinguished by sand or a wet cloth.

LABORATORY DIRECTIONS.

Never work with apparatus that is dusty or otherwise untidy. A cloth should always be at hand with which to clean apparatus. Leave apparatus clean and dry when through with an experiment. Be as careful, too, with the table-top. Leave no papers scattered around, either on the table or floor. Soap and towel should always be available for personal use.

On entering the laboratory each day inspect your table and all apparatus which you use in common with other pupils, and see that everything has been left as it should be. If anything is unsatisfactory, report it to the instructor *at once*, otherwise you will be held responsible. When you leave, see that everything is left properly.

When possible, prepare yourself for the work to be done before going to the laboratory.

Each pupil is to work alone unless lack of apparatus forbids it. There is to be no talking, except what is absolutely necessary for the work. If questions must be asked, question the instructor.

Have a place for everything and keep it there, unless it is actually in use. Throw away nothing unless positive that it is of no further value. Throw nothing but water in the sink. All other waste is to be placed in the jar or other receptacle provided for it. Broken articles are to be replaced.

The metric system is to be used in all work unless it is specifically stated to the contrary. All measurements should be made accurately, estimating to tenths of the smallest divisions used. *Decimal fractions exclusively are to be used.*

Repeat an experiment as many times as may be necessary to secure satisfactory results. As soon as an experiment is finished satisfactorily, begin with the next in order.

THE LABORATORY NOTES.

The pupil must keep very accurate notes of all his work. This may be done in an ordinary blank book, but for many reasons it is preferable to use loose sheets which are punched for binding within covers prepared for that purpose (see note at bottom of p. xxii). The notes will necessarily be of two kinds — those written in the laboratory concerning work actually done there, and those written elsewhere, including notes on work done by the instructor. These two kinds of notes should be distinguished from each other either by a different color of ink, or by writing them, one on the left-hand page of the book, the other on the right. This may be done whether loose sheets or a bound notebook be used.

All observations made in connection with an experiment should be noted *at once,* and *just as indicated* by the apparatus in use, without any correction or change whatever. If any such change is to be made, it also should be indicated. One may then know later whether such required changes have been made. All necessary observations should be made in the laboratory, and while the apparatus is set up, while lengthy computations should be made outside the laboratory hour, unless they are needed for immediate use.

Every figure that it is found necessary to make, in all numerical work should be placed with the work itself. The simple indications of multiplication or division will not suffice. All the work must be written in full on the paper.

The pupil should have a small notebook in which to make, for his own use, a note of all results obtained in any work.

At the end of each laboratory hour, brief notes of the work done during the hour must be left with the instructor. These notes will form the basis of judgment as to the value of the hour's work. See that they tell the *exact truth.* Be sure that all *numerical* results are included.

All notes should be in tabular form when possible (see form in Exp. 1). When this is not possible, the notes must be grammatically correct, with a subject and predicate in each sentence, and embrace the question asked or implied. Very often results are to be noted even if no specific question is asked.

Do not crowd the notes. If the notes of two different experiments occur on the same page, separate them by a generous space. Use a diagram or sketch whenever it will serve to make the meaning clear.

Do not "jump at conclusions." Nothing should be stated unless it is warranted by the experiment. The question is not, "What do I think ought to be the result?" nor, "What does some one else obtain for a result?" but, "What is my result?"

Give *your* results, not your neighbor's, nor those of the text-book. Two persons will seldom agree on the *same* measurement, yet they may occasionally.

Write all notes with ink. Errors indicated by the instructor should be corrected with ink of a different color. *Make no erasures.* Every mark made from day to day should remain to the end of the year.

Arrange all notes under heads as follows:

1. *Date, Name,* and *Number of Pupil.*

2. *Object.* State what the experiment means to you.

3. *Apparatus.* Describe briefly the apparatus used, with the number of each piece. Describe material also.

4. *Operation.* Describe the experiment. Here state exactly what was done, and everything that has any bearing on the success of the experiment.

5. *Data.* Give all numerical data. Give here the figures as read from any instrument, with corrections, if any. If several similar quantities are recorded, arrange them in tabular form. Quantities that depend upon each other should be arranged in parallel columns.

6. *Results.* Derive your results. Under this head indicate the mathematical work. Results may often be included in the tables referred to under 5. In this case they should be placed in columns with appropriate headings.

7. *Conclusions.* Under this head derive laws or state any general conclusions which are warranted by the results.

8. *Sources of Error.* Examine the method of work critically, and indicate any portions which seem to you to offer chances for inaccurate work.

Sometimes 5, 6, 7, or 8 may be combined or even omitted.

As soon as inspected sheets are returned to the pupil, errors are to be corrected by the pupil with ink of a different color, and the sheets bound in covers provided for that purpose. Frequently an entire experiment will need to be worked again. At irregular intervals these books will be inspected.

SIGNIFICANT FIGURES.

Significant figures are the figures which remain to a number or decimal fraction after the ciphers at the right or the left are canceled; thus, the significant figures of 20,500 and of 0.000205 are 205.

In all measurements keep one more decimal place than is *known* to be correct; thus, suppose we find three measurements of the same dimension to be 125.5, 125.8, 125.7 mm., the last figure being estimated in each case. The sum of these is 377.0 mm., and the mean is 125.666 +, or 125.66⅔, or 125.667 mm., none of which is proper. Each of these three results assumes to be more accurate than we have any authority for; moreover, the second is irrational in its combination of a decimal with a common fraction. As the 5 in units place is the last figure of which we are sure in the mean, we should keep the next figure, 6, in tenths place, and drop the rest; but as the following figure is greater than 5, we call the figure in tenths place one greater than it really is and call the result 125.7 mm. On the other hand, do not neglect to claim for a result all it is really worth as regards accuracy. For instance, the above sum is stated as 377.0 mm. It would not be sufficient to state this as 377 mm. simply, as this would imply that we knew nothing of tenths place, whereas we have good reason for thinking it should be 0 rather than 6 or 4, etc.

An investigator who carelessly keeps a greater (or a less) number of figures than are actually known to be correct, not only deceives himself, but often misleads others in regard to the accuracy of his work. Consider the following:

A cylinder measured by the vernier caliper is found to be 5.215 cm. long and 3.124 cm. in diameter. The vernier caliper cannot measure accurately thousandths of a centimeter, and the last figure of each of the above numbers is in doubt. The true length and the true diameter of the cylinder may be either greater or less than these values by 0.002 or 0.003 cm. It is desired to determine its volume. This may be calculated by the formula $v = h \times \pi r^2$ (see Appendix, p. 287). The radius r is 1.562. Proceeding according to the formula,

$$\begin{array}{r}
1.56\mathbf{2} \\
\underline{1.56\mathbf{2}} \\
\mathbf{3\,124} \\
93\,\mathbf{72} \\
781\,\mathbf{0} \\
1\,56\mathbf{2} \\
\hline
2.439\,\mathbf{844}
\end{array}$$

Since 2, the last figure in the value of the radius, is in doubt, all that depends upon it will be in doubt; that is, the figures printed in heavy-faced type. Keeping, then, only the first of the doubtful figures, proceed with the calculation.

$$\begin{array}{r}
2.43\mathbf{9} \\
\underline{3.14159} \\
\mathbf{21951} \\
1\,219\mathbf{5} \\
2\,43\mathbf{9} \\
97\,\mathbf{56} \\
243\,\mathbf{9} \\
7\,31\mathbf{7} \\
\hline
7.662\,\mathbf{33801}
\end{array}
\qquad
\begin{array}{r}
2.43\mathbf{9} \\
\underline{3.1415} \\
1\,219\mathbf{5} \\
2\,43\mathbf{9} \\
97\,\mathbf{56} \\
243\,\mathbf{9} \\
7\,31\mathbf{7} \\
\hline
7.662\,\mathbf{1185}
\end{array}
\qquad
\begin{array}{r}
2.43\mathbf{9} \\
\underline{3.141} \\
2\,43\mathbf{9} \\
97\,\mathbf{56} \\
243\,\mathbf{9} \\
7\,31\mathbf{7} \\
\hline
7.660\,\mathbf{899}
\end{array}$$

In the first multiplication above, the value of π, 3.141592, etc., has been cut short to 3.14159; in the second case, to 3.1415, and in the third to 3.141. It is seen that the product is as accurate in the third case as in the first, as regards the known figures (the first three), and with much less labor. Since we do not know whether the next figure should be 0, 1, 2, or some other digit, we are warranted in retaining in the multiplier only the same number of figures as there are in the multiplicand. We therefore drop the 5 and the 9, the last figures of the multiplier. *This prepares us for the statement that no result is any more accurate than the least accurate factor of which it is composed.* Even though we know the value of π to five decimal places, or even to a hundred or more, as is actually the case, only the first four figures are of value to us in this instance, as only three places are *known* in the other factor. Continuing with the calculation,

$$\begin{array}{r}
7.66\mathbf{1} \\
\underline{5.21\mathbf{5}} \\
\mathbf{38\,305} \\
76\,6\mathbf{1} \\
1\,532\,\mathbf{2} \\
\underline{38\,305} \\
39.9\mathbf{52\,115}
\end{array}$$

This gives as a final result 39.95 cc. as the volume required. Work a problem in this way, and then again, keeping all figures, and a remarkable saving of time will be noticed. In your work then,

I. In making any measurement keep one more place than is known. (Estimate to tenths of the smallest division used in the measurement.)

II. If you are dealing with several factors, either multiplying or dividing, keep no more places in the most accurate than you do in the least. The same is true of the product or of the quotient.

Interpretation of Results.

There are two general methods of comparing the results obtained in experimental work.

I. **Mathematically.** A very common method of comparing results is by means of a proportion. For example, if the four quantities a, b, c, d have such a relation to each other that $\frac{a}{b} = \frac{c}{d}$, or $a : b :: c : d$, as in Table I, then c and d are directly proportional to a and b. But if as in Table II, $\frac{a}{b} = \frac{d}{c}$ or $a : b :: d : c$, then c and d are inversely proportional to a and b.

Sometimes it is necessary to square or cube or to extract a root of two of the terms before a correct proportion can be obtained; as in Table III, $a^2 : b^2 :: c : d$, or $a : b :: \sqrt{c} : \sqrt{d}$.

Table I.

a	b	c	d
3	4	6	8

Table II.

a	b	c	d
6	2	3	9

Table III.

a	b	c	d
2	3	4	9

When two sets of results, as A and B, Table IV, are obtained, if the quotients arising from dividing each number in the one set by its corresponding number in the other set, agree, then these two sets of results are said to be directly proportional, or in direct ratio to each other. For example, if the results in A divided by the results in B ($A \div B$) give the same quotient in every case, then B is *directly* proportional to

A, or B varies directly as A varies, that is, as A increases B also increases, and *vice versa.*

If, on the other hand, the products of corresponding numbers are the same in every case, as, if $A \times B$ always gives the same product, then these two sets of results are ***inversely*** proportional to each other, or B varies inversely as A, so that, as A increases B decreases, or *vice versa.*

In most cases the quotients or products will not be exactly equal, owing to errors in the work. In general, however, if the first two "significant figures" (see p. xviii) agree in such quotients or products the law may be stated.

If there are some variations the law may be said to be approximately proved within the observed range, especially if the majority of the products or quotients agree well with each other.

II. **Graphically.** When two sets of results are obtained, so connected that any change in one causes a change in the other, they may be compared graphically. This affords an accurate and convenient method of recording results.

Use **cross-section paper,** which is paper printed or ruled in squares.[1] One of the lower left-hand intersections is ordinarily selected as the **origin** O, see figure, page xxiv. The horizontal line OX passing through the origin is called the **axis of abscissas** or **axis of X,** the vertical line OY, the **axis of ordinates** or **axis of Y.**

To "plot the curve" let one space (1 cm.) on the paper represent a certain number of units. For example, if 1 cm. on the paper represents 2 g., then a distance of 9 cm. reckoned from the origin will represent 18 g., etc.

---

[1] The paper used in the Chicago schools is accurately printed (not ruled) in 2 mm. squares, every fifth line being made heavy. This paper may be obtained of W. M. Welch & Co., 179 Illinois street, Chicago, in sheets about 8 × 10 in. punched for binding and furnished with hinged covers of stiff board, for about 30 cents per hundred sheets.

One of the two sets of results should be laid off on the axis of X; the other, on the axis of Y.

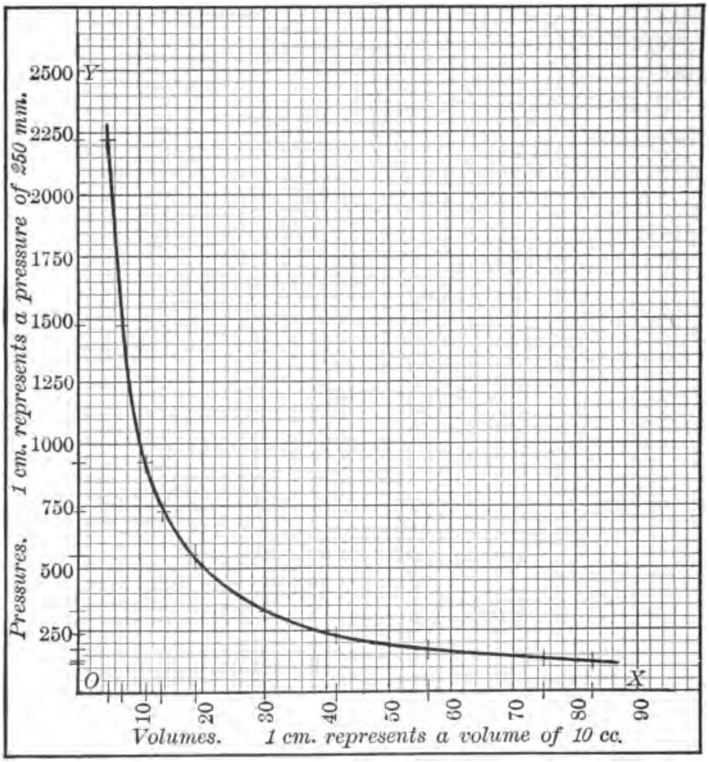
The same scale need not and often cannot be used for both the axis of X and the axis of Y. This will change the direction but not the character of the resulting curve. Such scales should be selected as will give as large a curve as possible and yet have all the data represented on the paper.

For illustration the following results and curve are given from actual work in the laboratory. It is desired to find the relation between the pressures (column A) and the volumes (column B) in a certain experiment. On the axis of X distances are laid off to represent the volumes, using a scale in which 1 cm. on the paper represents a volume of 10 cc. On the axis of Y a scale is used in which 1 cm. on the paper represents a pressure of 250 mm.

TABLE IV.

A Pressures	*B* Volumes
122.9 mm.	82.9 cc.
133.7	75.0
183.3	56.1
245.8	41.4
333.8	30.0
550.0	18.7
737.5	13.8
920.5	10.9
1475.0	6.9
2212.0	4.6

On the axes of X and Y, beginning at the origin, O, mark on each heavy intersecting line the number corresponding to it according to the scale adopted. Write also the scale used. Taking the first pressure, 122.9 mm., make a dot on the axis of Y at the proper distance from the origin. Then do the same with the first volume 82.9 cc. on the axis of X. At the intersection of normals passing through these two dots, make a third dot. This will locate one point in the curve because it represents both a pressure and a volume. Repeat, using the second pressure and volume. Then each pressure and volume in turn until all are located on the paper. Connect the dots thus located with a smooth and regular line or curve. This line will be the **curve** required. It is called a "curve" although it is frequently a straight line. When it is a straight line the two sets of results compared are directly proportional to each other. If it is a line of slight curvature the proportion is approximately true within the range of the data.



If the curve is found to be so located that, proceeding from one end toward the other, both axes (X and Y) are approached or receded from at the same time (not necessarily at the same rate), the two sets of results are *directly* proportional to each other. If, however, as in the case above considered, one axis is approached while the other is receded from, then one set of results diminishes while the other increases. If the line is straight, one set diminishes in direct proportion as the other increases. If the line is curved, the law may be that one set varies inversely as the other, as in the above case; or it may be that some other law holds.

The graphic method may farther be used to answer such a question as the following: What pressure would correspond to a volume of 24 cc.? Find on the axis of X the point corresponding to 24 cc. The corresponding point in the curve will locate a point on the axis of Y which will give the required answer, in this case about 425 mm.

The greater the number of observations (the more numbers there are in the sets of results), the more accurate the curve will be. On account of errors of observation the curve may be a *broken line*, thus showing at once where the error was made. In plotting curves use a hard pencil, well sharpened. Negative ordinates are laid off below the origin, negative abscissas, to the left.

Equivalents for the Exercises Required for Admission to Harvard University as Given in the Harvard Pamphlet.

Harvard	Equivalent	Harvard	Equivalent	Harvard	Equivalent
1	5, 6	22	130	43	69
2	37	23	130	44	67
3	40, 41	24	130	45	63
4	42, 43	25	130	46	68
5	38	26	17	47	—
6	50	27	17	48	114
7	44, 46, 47	28	14, 15	49	118
8	23	29	13	50	80
9	26	30	13	51	87, 94
10	24, 25	31	16	52	94
11	—	32	48, 49	53	—
12	Appendix, p. 269	33	35	54	91
13	21, 22	34	31	55	91
14	30	35	—	56	97, 98
15	30	36	—	57	102
16	125	37	—	58	95
17	126	38	—	59	—
18	127	39	57, 58	60	108
19	127	40	64	61	108
20	129	41	—		
21	128	42	66		

LIST OF EXPERIMENTS FOR SMALL SCHOOLS.

The following list of experiments is suggested for schools where apparatus and time are limited:

MEASURING AND PROPERTIES OF MATTER	1 2 6	10 12 13
MECHANICS	18 19 20 23 28 29	32 35 36 37 38
SPECIFIC GRAVITY	39 40 42	46 49 50
HEAT	53 54 55 56 60	61 62 63 67
MAGNETISM	71 73 74	75 78 80
ELECTROSTATICS AND ELECTRIC CURRENTS	82 86 87 88 89 90	91 92 95 96 107
SOUND	111 113 114	115 120
LIGHT	122 123 124	126 128 130

REFERENCE BOOKS.

The following list of books is recommended for every laboratory. Those marked with a * are especially useful and valuable. The price, publisher, and as far as possible the date of the last edition are given.

* AMES. Theory of Physics. $1.60. 1897. Harper and Bros.

* AMES and BLISS. A Manual of Experiments in Physics. $1.80. 1898. Harper and Bros.

APPLETON. School Physics. $1.20. 1891. American Book Co.

* ATKINSON. Dynamic Electricity. $2.00. 1891. D. Van Nostrand & Co.

AVERY. School Physics. $1.25. 1897. Sheldon & Co.

* AYRTON. Practical Electricity. $2.00. 1897. Cassell & Co.

BARKER. A Text-Book on Physics. $3.50. 1892. Henry Holt & Co.

* CARHART. Primary Batteries. $1.50. 1891. Allyn & Bacon.

CARHART and CHUTE. Elements of Physics. $1.20. 1897. Allyn & Bacon.

CREW. The Elements of Physics for Use in High Schools. $1.10. 1899. Macmillan & Co.

DANIELL. Principles of Physics. $4.00. 1895. Macmillan & Co.

DESCHANELL. Natural Philosophy. $5.75. 1890. D. Appleton & Co.

DOLBEAR. Art of Projecting. $2.00. 1887. Lee & Shepard.

DOLBEAR. Matter, Ether, and Motion. $2.00. 1892. Lee & Shepard.

* EVERETT. C. G. S. System of Units. $1.25. 1891. Macmillan & Co.

GAGE. The Elements of Physics. $1.12. 1898. Ginn & Co.

GAGE. Principles of Physics. $1.30. 1895. Ginn & Co.

Ganot. Physics. Translated by Everett. $5.00. 1898. Wm. Wood & Co.

* Hall and Bergen. A Text-Book of Physics. $1.25. 1897. Henry Holt & Co.

Harper. Scientific Memoirs. Edited by Professor Ames. 50 cents to $1.00. 1898. Harper & Bros.

* Hastings and Beach. General Physics. $2.75. 1899. Ginn & Co.

Holman. Matter, Energy, Force, and Work. $2.50. 1899. Macmillan & Co.

Hopkins. Experimental Science. $4.00. 1898. Munn & Co.

Houston and Kennelly. Elementary Electro-Technical Series. 10 volumes. $1.00 each. 1895. W. J. Johnston Co.

Induction Coils, How to Make. 50 cents. 1881. D. Van Nostrand & Co.

Jenkins. Electricity and Magnetism. $1.25. 1891. Longmans, Green & Co.

Jones. Elementary Lessons in Heat, Light, and Sound. 70 cents. Macmillan & Co.

* Kempe. Handbook of Electrical Testing. $7.25. 1887. E. & F. N. Spon.

Kohlrausch. Physical Measurements. $4.00. 1894. D. Appleton & Co.

Lodge. Modern Views of Electricity. $2.00. 1892. Macmillan & Co.

* Lodge. Elementary Mechanics. $1.50. 1890. D. Van Nostrand & Co.

Maxwell, J. Clerk. Elementary Treatise on Electricity. $1.90. 1888. Clarendon Press.

Maxwell, J. Clerk. Matter and Motion. 50 cents. 1892. D. Van Nostrand & Co.

Nichols. Outlines of Physics. $1.40. 1897. Macmillan & Co.

Nichols. Laboratory Manual. 2 vols. $6.25. 1894. Macmillan & Co.

Norrie. How to Make Induction Coils. 50 cents. 1896. E. & F. N. Spon.

* PICKERING. Elements of Physical Manipulation. 2 vols. Vol. I, $3.00. 1897. Vol. II. $4.00. 1894. Houghton, Mifflin & Co.

POYNTING and J. J. THOMSEN. Sound. $3.00. 1899. J. B. Lippincott Co.

SABINE. Laboratory Manual. $1.25. 1898. Ginn & Co.

* SLOANE. Arithmetic of Electricity. $1.00. 1891. N. W. Henly & Co.

* SLOANE. Dictionary of Electricity. $3.00. 1897. Munn & Co.

* STEWART and GEE. Elementary Practical Physics. 3 vols. $4.85. 1889. Macmillan & Co.

STEWART and GEE. Vol. I. General Physical Processes. $1.50. — Vol. II. Electricity and Magnetism. $2.25. — Vol. III. Practical Acoustics. $1.10.

TAIT. Lectures on Some Recent Advances in Physical Science. $2.50. 1885. Macmillan & Co.

* TAIT. Properties of Matter. $2.25. 1894. Macmillan & Co.

TAIT. Heat. $2.00. 1889. Macmillan & Co.

TAIT. Light. $2.00. Macmillan & Co.

* THOMPSON, SILVANUS P. Elementary Lessons in Electricity and Magnetism. $1.40. 1897. Macmillan & Co.

THOMPSON, SILVANUS P. The Electro-Magnet. $6.00. 1891. E. & F. N. Spon.

THOMPSON, SILVANUS P. Lectures on the Electro-Magnet. $1.00. 1892. W. J. Johnston Co.

TREVERT. Dynamos and Electric Motors. 50 cents. 1891. Bubier Publishing Co. Lynn, Mass.

* TYNDALL. Heat, a Mode of Motion. $2.50. 1867. D. Appleton & Co.

* TYNDALL. Sound. $2.00. 1875. D. Appleton & Co.

* U. S. Weather Bureau. Instructions for Voluntary Observers. Government Printing Office. Washington, D. C.

* U. S. Weather Bureau. The Barometer. Government Printing Office. Washington, D. C.

WENTWORTH and HILL. A Text-Book of Physics. $1.15. 1898. Ginn & Co.

* WRIGHT. Light. $2.00. 1892. Macmillan & Co.

WRIGHT. Optical Projection. $2.25. 1895. Longmans, Green & Co.

BONNEY, G. E. Induction Coils. $1.00. Whittaker & Co.

CAJORI, F. A History of Physics. The Macmillan Co.

ROUTLEDGE, ROBT. A Popular History of Science. Geo. Routledge & Sons.

THURSTON, R. H. Growth of the Steam Engine. D. Appleton & Co.

SNYDER, W. H., and PALMER, I. O. One Thousand Problems in Physics. 55 cents. 1900. Ginn & Company.

MANUAL OF EXPERIMENTAL PHYSICS.

INTRODUCTORY EXPERIMENTS.

MEASURING.

General Note. — 1. In all work in measuring, the *same* dimension should be measured at least three times, giving each of these measurements in your notes; then find the average of them and call that your result. In averaging measurements, continue the division to one decimal place of the smallest unit used during the actual measurement, and drop the rest (see "Significant Figures," p. xviii). If the first three measurements agree reasonably, they will suffice. If any measurement is evidently wrong, discard it and obtain another in its place. In general, if measurements of the same dimension vary more than one-tenth of one per cent, they are unsatisfactory. The several measurements of the same dimension are worthless unless they are absolutely independent of each other.

Whenever a measurement of any kind is obtained, make a note of it as it is read from the instrument used, before *correcting* it or making *any change whatever* in it.

2. When working with the metric system, estimate to tenths of the smallest division of the scale used, and record results in the decimal form, thus: 3.1472 m., *not* 3 m., 1 dm., 4 cm., 7.2 mm. In general, any distance less than a meter should be stated in centimeters, or if less than a centimeter, in millimeters.

Experiment 1. Practice in the Use of the Metric System.

Apparatus. — Meter stick; combination metric and English scale about 10 cm. long; caliper as in Fig. 1; brass tube to be measured; tumbler with flat bottom inside; sphere; metric graduate; water.

Note. — Notice that on one side of the meter stick are metric units, and on the other side, English.

Errors which arise from having the eye at one side of its proper position, as shown in Fig. 2, are called errors of **parallax.** In making any measurement, place the stick so that the edge of the graduated side is in contact with the surface to be measured, as in Fig. 3. With the scale in this position, parallax may be practically eliminated.

Often the end of the stick has been worn away, so it is best to begin with some division line near the end instead of with the end itself; especially is this true if it is desired to measure the distance between two lines on a given surface. This is also shown in Fig. 3.

Directions. — *a.* With the short scale measure the length and width of the table-top, taking three or more independent measurements and averaging the results. Repeat the *same* measurements, using the meter stick. Make the measurements in both the metric and English systems and place the work in the following form:

No. of the Table ....

Trial	With the Short Scale				With the Meter Stick			
	Length		Width		Length		Width	
	Meters	Inches	Meters	Inches	Meters	Inches	Meters	Inches
1								
2								
3								
Sum								
Mean								

Do the results obtained when using the meter stick exactly agree with those obtained when using the short scale? If not, what reason is there for thinking one method more accurate than the other? Keep this principle in mind in future work.

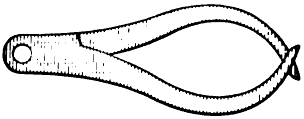


FIG. 1. — Exterior and Interior Caliper.

b. From the work above, calculate and state the value of a meter in inches, and the value of an inch in centimeters.

c. With the caliper obtain the outside diameter of the brass tube. Place the caliper on the meter stick and obtain the diameter in millimeters, estimating to *tenths* of a millimeter. Make three or more measurements at different places on the tube and average results, as in *a*, using the metric system only.

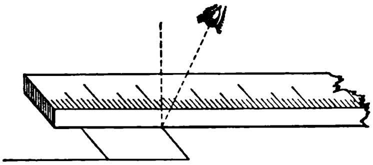


FIG. 2. — Incorrect Method of Using Meter Stick.

d. Measure the diameter of the sphere in the same manner, taking care to select three diameters at right angles to each other.

e. With the caliper measure the interior diameter of the tube. Close the caliper when through using it.

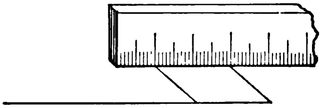


FIG. 3. — Correct Method of Using Meter Stick.

f. Compute the surface of the sphere and the exterior, interior, and end surfaces of the tube. (For method of computation see Appendix, p. 287).

g. Compute the volume of the sphere and of the brass in the wall of the tube.

h. Make the necessary measurements and compute the capacity of the room: (1) in cubic feet; (2) in cubic meters; (3) in gallons; (4) in liters.

i. What is the length in mm. of a leaf of this book? What is the length of the longest printed line on this page?

j. Draw in your notebook three straight lines with lengths of 2.57, 3.34, and 6.49 cm., respectively.

k. With the caliper measure the interior diameter of the tumbler at the top and bottom. Place a straightedge across the top of the tumbler and measure its depth. Compute its capacity in cc. (see p. 287). Test the accuracy of the work, using the **graduate** (Fig. 4) for the purpose. What is found to be the amount of error? What is the percentage of error?

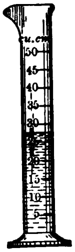


FIG. 4.
Graduate.

Experiment 2. The Vernier Caliper.

Apparatus. — A metric vernier caliper; a meter stick; the tube and the sphere of Exp. 1; (a barometer with a vernier).

Explanation. — The vernier caliper (Fig. 5) consists essentially of two parts, one of which slides along the other. On each of these parts a scale is engraved. Articles to be measured are placed between the jaws *A* and *B*. *C* and *D* may be used in the same way, except that they serve especially in such work as measuring the thickness of the wall of a tube, etc. *A* and *B* may be used as an inside caliper by adding to the observed reading the thickness of the two projections *A* and *B*, as determined by measuring them. The sliding scale *H* is called **a vernier.** The other scale *K* we will speak of as the **large scale.** Bear in mind that a **scale** means a **measure,** and does not include the extra material, brass, wood, steel, etc., which extends beyond the graduated part at either end. Note that in all scales the first line is called the zero line or line 0; the next, line 1; the next, line 2, etc.

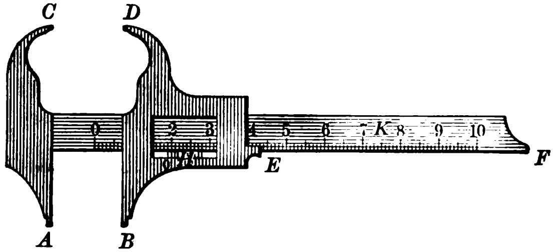


Fig. 5. — Vernier Caliper.

Directions. — *a.* By comparing the large scale with the scale stamped on a meter stick, determine the value of the smallest divisions of the large scale. Look carefully and see if the two scales agree *exactly* at all points. Possibly they do not. Perhaps this suggests that one is more accurately made than the other; one being on wood, the other on metal.

b. Note that when the caliper is closed the zero line of the vernier exactly coincides with the zero line of the large scale.

While the caliper is thus closed determine:

1) The length of the vernier (sliding scale).

2) The number of spaces into which the vernier is divided.

3) The length of each of these divisions of the vernier.

4) The difference in length between the smallest division of the large scale and the smallest division of the vernier. This difference determines to what part or fraction of the smallest division of the large scale a measurement can be made with this instrument. In other words, this difference is the "smallest variation" noticeable. What is this difference for this particular instrument? Report this to your instructor.

c. Set the vernier so that its zero line will coincide with the line marked 2 on the large scale (remember that the first line is called line 0), and do not move it until ¶ *d* is reached. What is now the distance from the zero line of the large scale to the zero line of the vernier? From the zero line of the large scale to line 1 of the vernier? To line 2 of the vernier? To line 3 of the vernier? To line 6? To line 8? 10? Report this last distance to your instructor for verification before proceeding with your work.

d. Close the caliper. The two zero lines coincide. How far must the vernier be moved to have line 1 of the vernier coincide with the first short line of the large scale? To have line 2 of the vernier coincide with the second short line of the large scale? line 3 with the third? line 6? line 9?

e. Once more with the caliper closed. Open the jaws of the caliper 0.1 (one-tenth) mm. Which line of the vernier now coincides with a .line of the large scale? Which one when the jaws have been opened 0.2 mm.? 0.4? 0.6? 0.8? 1.0?

f. Place the jaws exactly 19 mm. apart. Which lines of the vernier coincide with lines of the large scale?

Place the jaws 19.1 mm. apart and answer the same question. Repeat at 19.2, 19.3, 19.4 mm., etc., to 19.9 mm., answering the same questions in each case. Place them 20.0 mm. apart. Which lines of the vernier now coincide with lines of the large scale?

g. Place line 7 of the vernier on the line numbered 5 of the large scale. What is now the distance of the zero line of the vernier from the zero line of the large scale? Report to the instructor. Compare this distance with the space between the jaws of the caliper. *Measuring with this caliper then, is in reality finding the distance between the two zero lines.*

h. Hereafter take the reading of the caliper in the following manner: Close the jaws *A* and *B* on the article you wish to measure. Keep in mind that in using this caliper, the question to be determined is the distance from the zero line of the large scale to the zero line of the vernier. With the caliper thus set for a reading begin at the zero line of the large scale and count the number of small divisions before reaching the zero line of the vernier. Suppose it is 17 (this would be 17 mm. in this case, or 1.7 cm.). Usually there will be a part of a division over, that is, the zero line of the vernier will not exactly coincide with a line of the large scale. The fractional part of a division which remains is determined by counting along the vernier from its zero line until a line is reached which is nearest in continuation of one of the lines of the large scale. Suppose it to be line 6 of the vernier. This means that the fractional space under consideration is six times the "smallest variation" mentioned in *b* (4) above. This means then that the space between the two zeros is 17.6

mm., cm., inches, feet or whatever the smallest units of the large scale may be (in this case mm.).

i. Measure with the vernier caliper if possible the *same* articles measured with the caliper used in Exp. 1, and compare results with the results there obtained. Close the caliper before returning it.

j. If there is in the laboratory a barometer reading by a vernier, take the reading as it stands (*do not touch the instrument*) and report to your instructor.

NOTE. — Although it is not shown in the figure, it is nevertheless true that the caliper may be used according to the following plan: The centimeter divisions of the large scale are numbered as shown; they are also numbered by a series of figures reading in the opposite direction to those shown in the figure. By reading both the large scale and the vernier in the opposite direction to that used in the above work, one can find the distance from F to E just as in the above work the distance from A to B has been found. This is true if when E and F coincide the *new* zero line of the vernier coincides with the *new* zero line of the large scale. This method is of service in finding an inside measurement which could not otherwise be accurately determined; for instance, the length of a tube closed at one end. Some calipers have this second scale engraved on the back side.

The idea of the vernier is made use of in many instruments other than calipers. There are several different kinds of verniers, but the one described here is the one most frequently met with. The same principle underlies all, so that any may be understood by proceeding as above.

Experiment 3. The Micrometer Caliper.

Apparatus. — A "ratchet stop" micrometer caliper as in Fig. 6; a meter stick; articles to be measured, such as paper; wires; wire nails; window glass; isinglass (mica); a hair.

Caution. — Hold the caliper in the left hand and turn the ratchet head *H′* with thumb and finger of the right hand. Note that when the ratchet head is turned, the head *H* turns with it. Sometimes the ratchet head is not supplied. In that case, grasp the head *H* very lightly so that the screw will stop as soon as the jaws *A* and *B* come in contact with the surfaces of the object to be measured and not mash or press it out of shape.

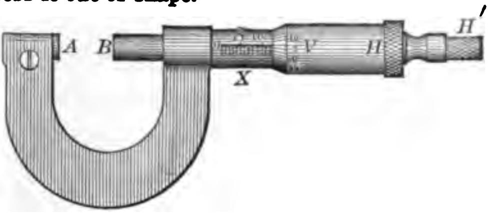


FIG. 6. — Micrometer Caliper.

Explanation. — Carefully inspect the instrument. Note that by turning the head the circular scale *V* not only turns but moves along the hub *X*, thus uncovering the linear scale *S* engraved on the hub. You will notice that every fifth line of the scale *S* is numbered; and, further, that these lines are crossed by a single line *O* running lengthwise of the hub. Never uncover the linear scale farther than to line 15.

Directions. — *a.* See that the contact surfaces of *A* and *B* are perfectly clean, then adjust the instrument so that *B* will be in contact with *A*. Continue to turn the ratchet head *H′* until, say, five clicks are heard. In this way one may always secure the same pressure between the jaws. The zero line of scale *V* should coincide with line *O* on the hub, when thus adjusted. If they do not coincide, note carefully their positions. Call this the "zero reading" of this instrument and make proper allowance for it in all readings. Open the caliper and determine the value of the scale divisions of *S*. They are generally either millimeters or fractions of an inch.

b. Place *A* and *B* in contact once more. Turn the head through exactly ten revolutions. How far has the edge of *V* moved along the scale *S*? What space now separates *A* and *B*? Do you need to measure this space to answer? How many divisions are there in the scale *V*? How many revolutions of *V* are required to open or close the jaws 1 mm.? Turning *H* through one division of *V* moves *B* through what space?

c. Set the instrument so that it shall read successively: 5.00 mm., 5.01, 5.05, 5.15, 5.155, 5.16, 5.25, 5.45, 5.49, 5.50, 5.51, 5.60, 5.70, 5.80, 5.90, 5.95, 5.99, 6.00 mm. Now set it to read 12.671 mm. and submit it to the instructor for examination.

d. Measure the thickness of a leaf of this book. Measure the thickness of the glass, mica, the diameter of the nails, wires, a hair, etc. Use very slight pressure with the hair. One click will suffice. Place results in tabular form.

e. Measure the *same* articles as were measured in Exp. 2, *i*, if possible, and bring together in one table for comparison the different results as obtained in these three experiments.

NOTE 1. — The pupil must clearly understand that all measurements made by him in this course are extremely rude, and scarcely comparable with the measurements of precision made by scientists. Measurements to the ten-thousandth of a millimeter and the twenty-thousandth of a second are frequently made, and no painstaking is deemed too great if it will increase the degree of accuracy attained.

NOTE 2. — If the caliper ever works unevenly or roughly, or feels as though there were grit in it, take it to your instructor at once.

This is a valuable instrument and should work with surprising smoothness. When not in use leave the caliper closed. Wipe the caliper thoroughly with an oiled cloth after using it. Every precaution should be taken to prevent rusting.

NOTE 3. — An approximate method for determining the diameter of wire when a caliper is not available is as follows: Wind as closely as possible, say, 25 turns of the wire around a cylinder 3 cm. or more in diameter. Measure the total width of the wire band on the cylinder and a simple calculation will determine the diameter desired.

Experiment 4. The Spherometer.

Apparatus. — A spherometer (Fig. 7); a piece of plate glass; a microscopic cover glass; a convex lens (or mirror); a concave lens (or mirror).

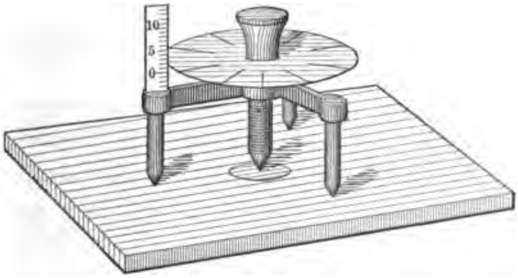


FIG. 7. — Spherometer.

Explanation. — A spherometer consists of a tripod with a micrometer screw in the center. This screw, being movable, may be made a *fourth* leg of the instrument, and on this fact depends its value as a measuring instrument.

Directions. — *a.* Determine the value of the units of the vertical scale.

b. How many small divisions are there on the large circular head? Turn the head till its zero line is at the vertical scale. Find by trial through how many divisions of the vertical scale the head is moved while it is turned through exactly ten revolutions.

Turning the head through one of its small circular divisions moves it through what space on the vertical scale? At the same time through what space is the point of the screw moved? Report this to the instructor.

c. Set the spherometer on the piece of *clean* plate glass and turn the head till the instrument rests equally on the four feet.

This may be determined in either of two ways.

First. If the screw works easily, turn it till it is somewhat above the surface of the glass, then lower it slowly and carefully, exerting pressure equally on the three legs, till the whole instrument barely moves on tapping one leg slightly with a finger or pencil; or

Second. Lower the screw till the instrument stands unsteadily. A very slight unsteadiness is readily noticeable to either the ear or the hand. The desired adjustment is obtained when the point of the screw *just* touches the surface.

Obtain several independent readings, recording each, and call the mean the "zero reading" of this particular instrument. Call distances above the zero line of the vertical scale positive (+); call those below negative (−). Are the four feet now in the same plane?

d. Lay a *clean* cover glass on the plate glass and determine its thickness in several places.

e. It is desired to determine the radius of the sphere of which the face of a given convex lens is a portion. To do this we must first consider a circle which is *absolutely* *independent* of the size of the sphere. This is to be done in two ways, as follows : *First.* With the screw at its "zero position," measure the distance from each of the three feet to the end of the screw. Call the mean the radius r' of a circle (not of the sphere, remember) passing through the three feet. *Second.* Measure the distance of the three feet from each other. Call the mean, one side of an equilateral triangle and compute the radius r'' of the circumscribed circle $ABCE$ (Fig. 8) thus: $BD = \frac{1}{2} BE$, and

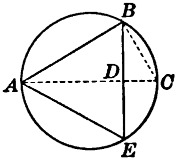


FIG. 8.

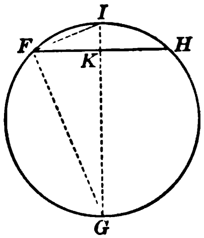


FIG. 9.

$AD = \sqrt{AB^2 - BD^2}$. From similar triangles $AD : BD = BD : DC$, or $BD^2 = AD \times DC$, and $DC = \frac{BD^2}{AD}$. Then $r'' = \frac{1}{2}(AD + DC)$. Compare this result with the value of r' first found, and call the mean the true value r.

f. Place the spherometer on the face of the lens in question, which we will consider to be a portion of the *sphere* $FGHI$ of Fig. 9, and locate the point of contact as in *c*. The difference between this reading and the zero reading will determine the height $h = IK$ of a segment of the supposed sphere. This segment, $FIHK$, will have for its base the circle passing through the three feet of the instrument, as explained in *e*, with its radius $r = KF$.

Let R be the radius of the *sphere*, then from similar triangles $IK : KF = KF : KG$, or $h : r = r : 2R - h$. $\therefore R = \frac{r^2}{2h} + \frac{h}{2}$. Thus find the radius of the sphere.

g. Test the curvature of the lens in various places, noting carefully in some way the position of each test.

h. In a similar manner determine the radius of the sphere of which the surface of the concave lens might be considered a portion.

Experiment 5. The Balance — Unit Mass — Standard Mass.

(*For the Instructor.*)

NOTE 1. — The instructor should have previously explained the difference between mass and weight; between unit and standard.

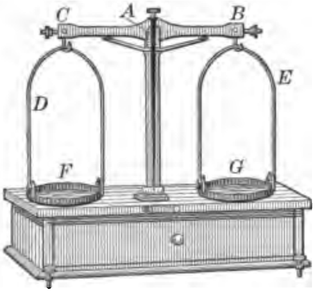


FIG. 10. — Balance.

Explanation. — The balance is an instrument used for the comparison of masses; it usually has the form of a lever with equal arms. As shown in Fig. 10, it consists of a rigid beam resting on a knife-edge or wedge, A, placed just above the center of gravity. Near the ends and at equal distances from the central knife-edge are placed two other knife-edges, B and C, on the upturned edges of which the bows D and E are hung. On these bows are placed the pans F and G. The masses to be compared are placed in these pans. The distances AB and AC are called the **arms** of the balance.

Caution. — The beam must never be free to move while the load in either pan is being changed. Do not touch either the beam or the pans while the beam is raised. The pans must be clean and the balance level. Test the balance gently when empty to see if the pointer vibrates equally on either side of the zero. If not, ask the instructor to adjust it.

Apparatus. — A balance; pieces of lead and wood; a pocketknife.

Directions. — *a.* Place a piece of wood on one pan of the balance and counterpoise it with a piece of lead; cut away part of one or the other until exact equilibrium is obtained.

b. Counterpoise another piece of wood with the same piece of lead (cut the wood if necessary; do not cut the lead) and then replace the lead by the first piece of wood which was counterpoised against it. Result? Counterpoise several pieces of wood in the same way.

What is noticed as to the relative sizes of pieces of the same kind of matter (wood) which balance each other? What of different kinds of matter? What can you say of two bodies, either of which counterpoises a third? Such masses as the lead and the two pieces of wood which counterpoised it are said to be **equal masses of matter,** whatever their difference in size or appearance. Would the relations of the masses of lead and wood as found in *a* and *b* be the same whether the arms of the balance were equal or not? Why?

c. Take several of the equal masses prepared in *b* and find how many of them are required to counterpoise a given piece of wood, cutting away part of this piece if necessary. Each of these equal masses might be called a **unit** mass (*e.g.*, an ounce or a gram).

We might if we chose call this unit mass our **standard mass** and determine all other unit masses, larger or smaller, by a reference to it. For instance, **a pound** being selected as our standard mass, it is thought best to select $\frac{1}{16}$ of this mass as a convenient unit for some purposes, so it is given a special name, the **ounce.** In just the same way 2000 of these standard units are taken together to form another unit convenient for other purposes and it is given the name **ton.** Similarly in the metric system, the **kilogram** is the standard, while the **gram** is the unit which will be used principally, in this course in physics.

d. Repeat *c* with a smaller piece of wood, using much smaller unit masses (pieces of matches or toothpicks are convenient). Do you find it necessary now to cut away more or less of the piece of wood than in *c* to secure an exact balance? If you had used separately each of these two sets of unit masses without cutting the piece of wood, in which case would the unit masses come nearer to counterpoising the piece of wood, *i.e.*, in which case would the error be less?

Which give the greater accuracy in weighing, large or small unit masses? Why?

Can absolute equality of two masses be obtained?

NOTE 2. — Instead of using a large number of these small unit masses, sets of masses consisting of a few pieces and so related as to give all possible combinations up to their sum are generally employed.

NOTE 3. — In practice, this counterpoising of masses is called "weighing," and the masses themselves are called "weights," though this is not correct.

Experiment 6. Weighing.

Reference. — Stewart & Gee, Vol. I, pp. 74, 75.

Apparatus. — A sensitive balance; a set of weights; a beaker; a burette and holder as in Fig. 11; water (preferably distilled); some article to be weighed.

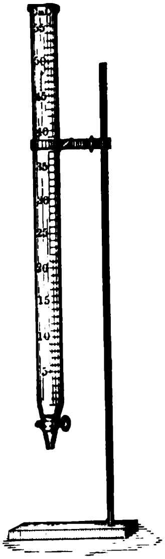


FIG. 11. — Burette.

Directions. — *a.* A good balance is so delicate an instrument that the utmost care is needed in using it. It is essential to the good preservation of the balance that when the indication of the pointer is not actually being read, the beam should be lowered from its bearings by a slow, steady movement. This operation should also relieve the knife-edges at the ends, of the weight of the pans. Do not use haste. Never carry the balance from one place to another without lowering the beam. Further, do not move the balance about more than is absolutely necessary.

b. Locate the balance well back on the table, so that there may be plenty of room; level it, and see that it is in good order, as follows: The whole balance, and especially the pans, must be free from dust. Partially raise the beam. If the pans swing back and forth, lower again, and repeat the raising and lowering till the pans rise quietly without vibrating. The long pointer should now swing very slowly from side to side, and finally come to rest at the zero (0). If the pointer vibrates equally on each side of the zero, it is evident that each successive swing will be a little less than the last, and that it will finally stop at zero. The observation of this decrease is just as satisfactory as to wait for it to stop at the zero. See Note 2. If the balance needs regulating, report to the instructor.

c. Notice that there is one weight for each pocket in the block. (Some manufacturers duplicate the 200, the 20, and the 2 mg. weights; others duplicate the 100, the 10, and the 1 mg. Sometimes these duplicate weights are to be placed in the same pocket with their equals, that is, two in a pocket.) See that the weights are in their proper pockets when you begin work and when you finish, likewise the glass cover and the tweezers. If any are missing, notify the instructor immediately. Be sure that there is no dust on the weights. Clean them with a cloth, not with the fingers.

d. The beaker or other object to be weighed, if perfectly dry and suitable, may be placed directly on the scale-pan; otherwise it should be weighed in a beaker whose weight must be determined separately (either pan may be used, though it is customary to place the object on the left-hand one). Now select the smallest weight which you consider *too heavy* and place it in the opposite pan. If you find that it is too heavy, return it to its place and try the next smaller. Continue thus until you find one which is too light. Leave this weight in the pan and add the next in order, skipping none unless you know it would be too heavy. Take each weight in its order. Proceed thus until equilibrium results. *Remember to lower the beam* from its bearings whenever any change is to be made in the weights in the pan. An accurate weighing is necessarily a slow process and should never be attempted when one is in a hurry. Whenever the larger weights are in the pan it is better to raise the beam a very small amount only and notice which way the index moves. The smaller weights must be handled only with the tweezers, as the moisture of the fingers would affect their accuracy. Those of 100 g. or larger may be taken up by the knob with the fingers, but no other part of them should be touched. Never lay the weights down except on the scale-pans or in their pockets in the block.

e. After securing equilibrium, determine the sum of the weights as they lie in the scale-pan, and as a check upon your work sum up the vacant pockets in the block.

f. Never place a weight in the pan with the article you are weighing, as that will complicate matters. Always keep them together on the same pan.

g. After securing equilibrium let the objects in the two pans exchange places, *i.e.*, the article to be weighed and the weights. Are they still in equilibrium? If so, the two arms of the balance are equal, as they should be. If not, your result as obtained in *e* will not be correct. In that case the correct result may be obtained as follows: Place the object to be weighed in one pan and counterpoise it with sand, lead chips, or some such substance in the opposite pan. Now remove the object from its pan and place weights in that pan just as though you were weighing the sand, until equilibrium again results. It is evident that the sum of these weights is exactly equal to that of the object, as each of them was counterpoised by the same amount of sand. This method is called **"Weighing by Substitution."**

NOTE 1. — If one of the small weights is ever placed in a pan containing sand, look after it carefully, as it is liable to be lost.

h. Weigh, or counterpoise with sand, the clean, *dry* beaker. Fill the burette of Fig. 11, held vertically in its holder, with distilled water. Draw out into some other vessel enough water to clear all the air out of the lower end of the burette and bring the surface of the water down into the graduated portion of the tube. This water is not needed. During the measurement which follows, the water level must not be below the graduated portion of the burette. Notice that the surface of the water is concave. Consider the water level to be that portion of the surface which is at the center of the tube; see *A* in Fig. 12, not the part *B*. Read accurately the position of the surface of the water in the burette. Draw out into the dry beaker about 30 or 40 cc., and read again very accurately the position of the water surface. (Do not try to obtain any definite volume; that is too troublesome.) The difference between these two readings determines the volume of water in the beaker. How great is this volume?

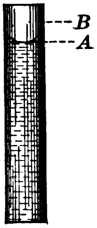


FIG. 12.

i. Weigh the water. Return the water to such place as may be indicated by the instructor. Calculate the weight of 1 cc. of water. Does your result agree with the statement found in the Appendix, p. 303? Column *Q* gives the weight in grams of 1 cc. of pure water at the temperature stated in column *t*. If there is any difference, how do you account for it? How much difference do you find? How much is the per cent of difference?

NOTE 2. — For method of determining the zero point of a balance, and for balance reading by vibrations, see Appendix, p. 267. To determine the sensitiveness of a balance, see Appendix, p. 268.

NOTE 3. — If more accurate work is desired, the temperature of the water should be taken immediately after drawing it from the burette and a correction applied to correspond. For instance, if the temperature of the water is found to be 20° C. (68° F.), the result in *i* should be multiplied by 0.99827, because of the volume of water at 20° being greater than at 4°, the standard (see Table XXV, p. 303).

PROPERTIES OF MATTER.

Experiment 7. Indestructibility.

(For the Instructor.)

Apparatus. — A piece of hard glass tubing about 20 cm. long and 2 cm. in diameter; two one-hole rubber stoppers to fit the tube; two pieces of glass tubing about 10 cm. long to fit the rubber stoppers; 2 pieces of glass tubing about 20 cm. long, bent at right angles near one end, and of the same diameter as the two short pieces; two pinchcocks; two pieces of rubber tubing about 10 cm. long to fit the small glass tubes; a vessel of water; a copper or iron oxygen generating retort; a Bunsen burner; stands for supporting apparatus, as shown in Fig. 13; 20 g. potassium chlorate; 5 g. pulverized manganese dioxide; a balance reading to 0.5 mg.; a little sugar charcoal; weights.

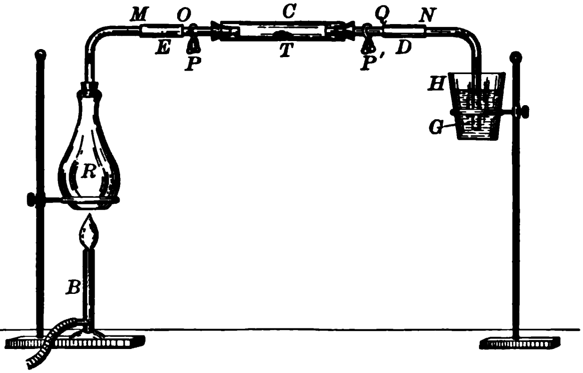


FIG. 13.

Directions. — *a.* Pulverize the potassium chlorate and mix thoroughly with the pulverized manganese dioxide, after which place the mixture in the retort *R*. Place about 0.005 g. of the charcoal in the hard glass tube *C* which has been fitted with the rubber stoppers and glass tubes. Slip the pinchcocks over the glass tubes and with the short rubber tubes connect the apparatus as shown in Fig. 13, supporting it with the stands. Wind two or three turns of wire around the rubber tubes at *O* and *Q* to prevent them from being blown off when the tube *C* is heated at *T*, as directed in *d* below.

b. Heat the retort strongly but carefully and when sure that all of the air has been expelled from the apparatus (test with a burning match), remove the flame and place the pinchcocks *P* and *P′* on the rubber tubes at *D* and *E*, respectively.

c. Disconnect the apparatus at *M* and *N*, being careful that the pinchcocks are not disturbed. Place the tube *C* with its connections on the balance and find its weight to 0.5 mg., or less if possible. (Or place the balance in equilibrium, the tube *C* with its connections being in one pan.)

d. Locate the charcoal at the middle of *C*, as shown at *T*, and return *C* and its connections to its support. Do not connect at *M* or *N*. Bring the flame under the tube at *T* and heat slowly and carefully. The charcoal will soon unite with the oxygen in the tube, leaving no residuum. Remove the flame as soon as the charcoal begins to glow.

Caution. — It is essential that the flame be kept near the middle of the tube, as rubber is very inflammable in the presence of oxygen.

e. Return the tube and its connections to the balance and again weigh. Has any matter been lost? Where is it?

NOTE 1.—It is preferable to use sugar charcoal, as other kinds will leave more or less ash after union with oxygen. This experiment is especially valuable on account of the complete disappearance of a solid.

NOTE 2.—It is possible to perform this experiment by using an ordinary ignition tube furnished with stopper and exit tube instead of the metal generating retort.

Experiment 8. Impenetrability.

Apparatus.—A bottle or flask of 100 cc. capacity or smaller; a two-hole rubber stopper to fit the bottle; a short thistle tube or a funnel; water.

Directions.—Through one hole of the stopper pass the thistle tube (if the tube sticks in the stopper, wet it) and place the stopper in the flask. Cover the other hole with a finger and rapidly pour water into the tube. Observe what takes place. Remove the finger and note result. Repeat.

Explain these actions which you have observed. If you can think of an original experiment to show this property of matter, perform it and write the notes on it.

Experiment 9. Porosity.

First Part.

Apparatus.—A long, slim test tube; water; alcohol (about 95 per cent).

Directions.—*a.* Fill the test tube about half full of water, then carefully pour in alcohol till the tube is filled, having previously inclined the tube as much as possible, to prevent the two liquids mixing. If this has been done satisfactorily, a distinct plane of demarcation may now be seen between the two liquids. On moving the tube slightly this plane may be seen to waver up and down.

b. Cover the tube carefully with the thumb so as to exclude *all* air. Invert quietly and observe. Have you ever before noticed anything which reminds you of what is now seen? If so, state it.

c. Turn the tube upright once more. Does the thumb appear to be pushed in? Tip back and forth slowly till the liquids are thoroughly mixed, always keeping the tube closely covered with the thumb. Note any change in volume. Explain what you have noticed.

d. Finally, very slowly withdraw the thumb, listening closely to see if you can hear any sound when so doing.

e. If results are unsatisfactory, repeat *a*, *b*, *c*, and *d*.

Second Part.

Apparatus. — A long, slim test tube; salt; water; a piece of gummed paper.

Directions. —*f.* Put enough salt into the test tube to fill about two-tenths of the tube. Carefully pour in upon the salt enough water to nearly fill the tube. Tap the tube lightly with a finger to disengage any particles of air entangled with the salt. Mark the level of the water by the piece of gummed paper, being careful to hold the tube vertically. Cover the tube closely with the thumb and proceed as in *c*, till no more of the salt will dissolve. Be careful that none of the water is lost, removing as little as possible on the thumb.

g. Is the water level now at the same height it was before the salt was dissolved? Explain.

What other material could have been used in place of the salt?

What does the experiment teach?

Is this result in opposition to the property of impenetrability?

What is your idea of the size of spaces between the particles of water?

Mention four porous bodies.

Experiment 10. Inertia.

First Method.

Apparatus. — A mass of about 6 kg.; ordinary cotton thread, about No. 24; a strong cord for suspending the mass.

Directions. — *a.* Suspend the mass by the cord so that it shall be at least a meter from the point of support. Tie the thread to the mass so as to swing it, and swing very gently at first. Attempt to stop the mass suddenly by the thread. Result? Repeat.

b. Tie the thread about the mass and try to start it swinging with a sudden jerk. Result? Repeat.

c. How does the force required to start or stop the mass suddenly, compare with the force required to break the thread?

Study the results in connection with Newton's First Law of Motion.

Second Method.

Apparatus. — A mass of 2 or 3 kg. in the form of a bag of sand or something similar; ordinary cotton twine.

Directions. — *d.* Suspend the bag of sand by a piece of twine 20 or 30 cm. long. Tie a similar piece of the same twine to the mass and let it hang loosely below the mass. Take hold of the lower end of this second piece of twine and pull steadily downward till the twine breaks. Which piece broke?

e. Arrange as before, but give a sudden jerk downward. Which piece broke this time? Why? How do you account for the different results in *d* and *e*? Repeat till satisfied that the results are correct.

f. Study the results and from them draw such conclusions as are warranted.

NOTE. — This second method may be varied by using a strong rubber band, or a coil spring for suspension in place of the upper piece of twine. Break the twine below, first, by a steady pull; second, by a jerk; third, by a pull which is a compromise between those two, and notice how far the mass moves downward each time.

Experiment 11. Cohesion of Water — Adhesion between Glass and Mercury.

Apparatus. — A rectangular or circular piece of *plate glass* with an area of about 75 sq. cm., arranged for horizontal suspension; a specific gravity balance with weights; lead chips or sand; a shallow glass or porcelain dish about 20 cm. in diameter; some clean water; mercury.

NOTE. — Arrange the glass plate for suspension as follows; cut off the threaded part of three small cup hooks and attach the hooks by sealing wax to the plate. Attach to each of these hooks a moderately stiff copper wire, about No. 16 or 18. By means of these three wires the plate may be suspended from the balance. Now to make the plate hang horizontally, simply bend one or two of the wires till the result is satisfactory.

Directions. — *a.* Suspend the glass plate, thoroughly cleaned, so that it will hang *horizontally* on the under side of the higher pan of the balance, as in Fig. 14, and counterpoise it by placing lead chips or sand in the other pan. Place the dish so that when water is poured into it the water will rise and touch the glass plate. Now pour in water till it just touches the plate when the beam is nearly or quite horizontal. Be sure that there is no water on the upper side of the plate. See that there are no air bubbles on the under surface. The plate must not touch the dish. The balance beam should now be in a nearly horizontal position. If not, it must be made so by either increasing or diminishing the quantity of water in the dish. Now place weights in the pan which holds the counterpoise of lead chips or sand, beginning with about 25 g., and adding carefully 1 g. at a time until the plate breaks away from the water.

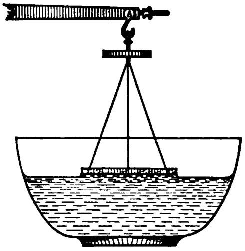


FIG. 14.

Caution. — There must be some kind of a "stop" to prevent the beam of the balance going too far when this takes place, or the result may be disastrous.

b. By examining the under side of the plate, determine whether it was pulled away from the water or the water itself was pulled asunder.

c. Find the total weight (in grams) placed in the pan.

d. Repeat the test twice, recording the results in each trial in the table below.

e. Compute the area of the plate in sq. cm. and find the force (weight) necessary to pull apart one sq. cm. of water.

Area of Plate in sq. cm. ....

Liquid Used	Total Weight (in g.)				Force to Separate 1 sq. cm.	
	Trial				In Grams	In Dynes
	1	2	3	Mean		
Water						
Mercury						

f. Why is it necessary to have the plate hang horizontally? What is the force which prevents the water from separating at first?

g. Dry the apparatus thoroughly and repeat the whole work, using mercury instead of water, beginning with 50 g. and adding 5 g. at a time (see Caution, p. 285).

h. How much is the error (see Table X, p. 293)? Percentage of error?

Experiment 12. Capillarity.

Apparatus.—A set of 3 or 4 tubes differing in size, the smallest having a diameter of 1 mm. or less, the largest about 5 mm.; a glass beaker; a tumbler; a wax candle; a strip of tin (tinned iron, ordinary sheet tin); a glass rod; a small bottle of alcohol; clean water; a neckless homœopathic vial (about ½ oz.) half filled with mercury; two pieces of glass, such as are used for microscope slides; a rubber band; a small piece of wood, such as a match or toothpick; distilled water.

Caution. — In this experiment it is extremely important that all apparatus and material should be scrupulously clean. Directions for cleaning the tubes will be found in the note below (see Caution, p. 285).

Directions. — *a.* Fill the beaker about two-thirds full of clean water. Study carefully the form of the upper surfaces of the mercury, alcohol, and water around the sides of the vessels. If the contact line between the water and beaker is rough and ragged, it means that the beaker is not clean. Clean the beaker. Now, if the line between the water and beaker is smooth and regular, you will understand the value of having all the apparatus thoroughly clean. Make a sketch of a vertical section of each of the surfaces — mercury, water, and alcohol.

b. Lower the glass rod to the bottom of the beaker of water. Raise it nearly out of the water. Notice the position the water takes around the rod. Remove the rod. Is it wet? Dry the rod and repeat with mercury in place of the water. Did the mercury wet the rod? *i.e.*, did it adhere to the rod? Repeat with alcohol.

c. Repeat *b*, using the wax candle in place of the glass rod, and answer the same questions. It may be necessary to clean the surface of the candle by scraping it.

d. Repeat once more, using the strip of tin in place of the glass rod, and answer the same questions. In this case, however, you must not use the mercury hitherto used, as it would soon become spoiled for other purposes. So use such mercury as may be indicated by the instructor. Throw away the tin after using.

e. Measure the interior diameter of each of the tubes as carefully as possible, using an ordinary mm. scale. Lower all the tubes to the bottom of the beaker of water so as to wet them inside. Now lift one of the tubes out of the water, dry the end and lower it very slowly toward the water, inclining it a little so that one corner approaches the water first. Result? Why?

f. Standing all the tubes in the beaker of water, take out the one with the smallest diameter first, and removing with the finger the drop of water at the lower end, measure and record the height of the water still remaining in the tube. Repeat this measurement twice, taking the mean of the three measurements. Repeat with the other tubes.

g. Repeat *f*, using hot water in place of cold water. See that the water is *boiling*, and that the tubes are made equally hot by standing them in the boiling water before making measurements.

h. Dry the tubes inside and outside as directed in the note below and repeat with alcohol in place of water. Identically the same tube must be used for each liquid.

i. Dry the tubes once more and place them successively in the vial of mercury. Hold the tubes against the side of the vial in order to get a better view of the result. This time keep them in the liquid instead of raising them from it as before. Is the level of the mercury in the tube higher or lower than the level in the vial outside? How much? Record this difference for each of the tubes.

j. Record the data as follows:

Diameter of Tube	Height in Cold Water	Height in Hot Water	Height in Alcohol	Depression in Mercury
. . . . mm.	. . . . mm.	. . . . mm.	. . . . mm.	. . . . mm.

k. Make a sketch of a vertical section through the middle of the tube, showing the shape of the cold-water surface in and around the largest tube.

l. Make a sketch as in *k*, showing the shape and position of mercury in and around the tube which is about 2 mm. in diameter.

m. Such a convex or concave surface of a liquid in a tube is given the name **meniscus.** In measuring the height of a liquid in a tube, always measure to the center of the meniscus surface ; not to the edge where the liquid touches the tube. This is the case whether the meniscus is convex or concave.

n. Place the small stick between the microscope slides parallel with and close to one of the long edges. Slip the rubber band over the slides to hold them in this position and thrust the slides thus prepared into water in order to wet them. Now raise them out of the water, keeping the stick vertical. Study the shape of the water surface. Make a sketch showing the shape of this surface. This curve is called a **hyperbola.**

o. What force causes the liquids to ascend in the tubes?

p. From your results can you see any relation between liquids which *do* or *do not* wet surfaces in contact with them, and the fact of their being raised or depressed?

NOTE. — If it is desired to measure accurately the diameter of the tubes, proceed as follows:

First clean them carefully with a solution of caustic potash by attaching to the tubes a rubber bulb from a pen-filler, and with it causing the liquid to flow back and forth through them. Rinse *thoroughly* in running water. Follow this with hydrochloric acid in the same way, and finally rinse as before. Both the acid and the potash are injurious to the hands.

Dry the tubes by forcing a current of dry air through them from a bellows (do not blow through them), the air being warmed by a Bunsen flame during its passage through a tube interposed on the way.

Weigh the tube accurately. Fill a portion or the whole of it with mercury. Measure the length of the mercury column. Call this l. Weigh the tube with the mercury in it. Find the weight of the mercury. Call this w.

If this mercury cylinder were a water cylinder, its volume v would be $v = \pi r^2 \times l$, where r is the radius; and if r and l were stated in cm., v would be given in cc. This then would give the weight in grams, or $w = \pi r^2 \times l$.

But it is a mercury cylinder and therefore is 13.6 times as heavy as a similar water cylinder; so for the mercury cylinder $w = \pi r^2 l \times 13.6$.

From this, $r^2 = \frac{w}{\pi l \times 13.6}$ and $r = \sqrt{\frac{w}{\pi l \times 13.6}}$.

State the value of r in mm., keeping three decimal places. Does this agree with the instructions concerning "Significant Figures," p. xviii?

Experiment 13. Elasticity of Flexure (Bending).

Apparatus. — Two pine rods, one 102 × 2 × 1 cm., the other 102 × 1 × 1 cm.; one maple rod 102 × 1 × 1 cm. (there should be on each rod a line at the middle and other lines at intervals of 10 cm. from this middle line in each direction); two triangular prisms about 3 or 4 cm. long and with faces about 2 cm. wide; an indicating apparatus, with a lever hung so that the long arm will be about 10 times the length of the short arm (see Fig. 15). The long arm, which serves as a pointer, must move vertically alongside of a millimeter scale; metric weights so that readings up to 2000 g. can be obtained.

Caution. — Use the greatest care in placing the weights on the rod in the order directed in *b*. See that the weights do not fall off and thus destroy the adjustment. If the adjustment is once destroyed, you must begin the test anew.

NOTE 1. — Ordinary iron weights are accurate enough for this experiment. Should the weights be placed *near the middle* of the rod? Must the long arm of the pointer necessarily be 10 times the length of the short arm? The weights might be placed in a pan suspended from the rod by a string passing through a hole in the table-top.

Directions. — *a.* Place the two prisms well back on the table with their upper edges exactly 100 cm. apart and parallel. On these support the larger of the two pine rods (see Fig. 15). Place the rod flat, not on edge. If it is already bent, place it so that the middle is higher than the ends. Place the short arm of the pointer under the middle of the rod so that the distance from the fulcrum of the pointer to the edge of the rod will be just $\frac{1}{10}$ the distance from the fulcrum to the outer edge of the vertical scale. Press downward lightly on the middle of the rod. The end of the long arm of the pointer will move 10 times as far as that of the short arm, *i.e.*, 10 times as far as the middle of the rod itself. This motion of the middle of the rod is what we wish to measure, but as its motion is so slight we will make use of the multiplying effect of the lever and read the various positions of the pointer instead of the rod itself. From this, one can calculate the motion of the rod. The pointer should now be nearly hori-

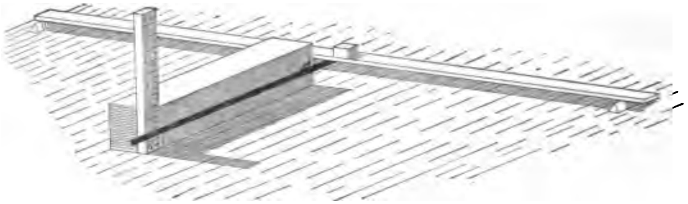


FIG. 15.

zontal, with the short arm slightly lower than the long one, and touching the rod only at its *edge*. If necessary, raise or lower a portion of the apparatus to produce this result.

b. Test I. Record the position of the pointer. Now, using the greatest caution possible so as not to disturb in any way the adjustment of rod and pointer, place weights on the middle of the rod, beginning with 200 g., and record the position of the pointer. Remove the weight and observe the position of the pointer as before. Does it return to its starting point? If not, allow it another moment before noting result. Use weights of 400, 600, 800, and 1000 g. Always remove the weight and record the position of the pointer without loss of time, as the results will be unsatisfactory if the weight is left on the rod for more than a few seconds.

c. Record your results as follows, noticing that columns 2 and 3 are the only ones requiring actual measurements. All the others may be *calculated* from them.

TEST I. PINE ROD FLAT. SIZE 1 × 2 CM. LENGTH 100 CM.

Load	Reading without Load	Reading with Load	Rise of Pointer in mm.	Depression of Rod in mm.	Depression of Rod per 100 g.
200 g.					
400 g.					
600 g.					
800 g.					
1000 g.					

d. Test II. Repeat Test I, except that the rod is to be placed on its narrow side and weights used of 500, 1000, 1500, and 2000 g.

NOTE 2.—Record the results of Tests II to VII, inclusive, as was done in *c*.

e. Test III. Use the same rod on its broad side, with the upper edges of the prisms 50 cm. apart, and the same weights as in Test II.

f. Test IV. Use the smaller pine rod, with the upper edges of the prisms 100 cm. apart, and weights of 100, 200, 300, 400, and 500 g.

g. Test V. Use the same rod as in Test IV, the prisms being 50 cm. apart. Use weights of 200, 400, 600, 800, and 1000 g.

h. Test VI. Use the maple rod, with the prisms 100 cm. apart, and weights as in Test IV.

i. Test VII. Use the maple rod, with the prisms 50 cm. apart, and weights as in Test V.

j. By a careful inspection of all of the tables, determine the relation between the force employed (the load) and the amount of flexure, *i.e.*, the relation between the first and fifth columns. State the law.

k. Comparing Test I with III, IV with V, and VI with VII, determine the relation between the length of rod and amount of flexure. State the law.

l. Test VIII. With the larger rod on its flat side and always with the *same* load (500 g.) midway between the supports, set the prisms at 50, 60, 70, 80, 90, and 100 cm. apart and note the depression.

m. Tabulate the data as follows:

TEST VIII. PINE ROD FLAT. SIZE 1 × 3 CM. LOAD 500 G.

Load	Length	Reading without Load	Reading with Load	Rise of Pointer in mm.	Depression of Rod in mm.	Depression of Rod per 100 g.	Square of the Length	Cube of the Length
500 g.	50 cm.							
500	60							
500	70							
500	80							
500	90							
500	100							

n. From a consideration of the results in Test VIII, state the law showing the relation between the depression and the length of a rod when the load is constant.

o. Plot your work as follows (see "Interpretation of Results," pp. xxi–xxv): For Test I, beginning near the lower left-hand corner of the paper with the intersection of two of the heavy lines as the "origin," call the horizontal heavy line the **"axis of X,"** the vertical one the **"axis of Y."** With a scale, say of 10 mm. on the cross-section paper representing 100 g. of the load, lay off on the axis of Y distances corresponding to the weights used; and on the axis of X, with a convenient scale, say 10 mm. on the cross-section paper representing 1 mm. of rod depression, lay off the depressions of the rod corresponding to the weights used. Now through the intersections of the normals erected from these pairs of points draw a curve. Though such a line as this may not seem to be a curve, and sometimes is really a straight line, it is called a curve. What kind of a line is it in this test? What does it show?

p. In a similar manner plot a curve from the data in Tests II, IV, and VI. These plots may probably all be made on the same sheet and from the same origin, care being taken to keep them distinct. What is the nature of the line in each test?

Experiment 14. Elasticity of Extension (Stretching).

Apparatus. — Two meter sticks or pieces of meter sticks about 20 cm. long; a small board into which have been partially driven two screws or nails; a clamp for holding this board to the table-top; a 15 kg. spring balance; about 2 m. spring brass wire, No. 28, B. & S.; a micrometer caliper; a screw and nut with hook (see Appendix, p. 269).

Caution. — A kink in the wire will spoil your work. Before each reading tap the balance lightly to loosen the pointer, and make sure that it takes its proper position.

Directions. — *a.* Clamp the board to the table-top near one end and arrange the apparatus as shown in Fig. 16.

Fasten one end of the wire to one screw, *A*, by soldering, or by winding it several times around the screw, then carrying the end to the other screw, fastening to the second screw in the customary manner. This will prevent the wire from slipping at the first screw, and also tend to eliminate any error of unequal tension in the wire caused by fastening in the usual manner. Place the wooden screw and nut *D* on the edge of the table, with the nut near the point of the screw (see Fig. 16). Slip the ring of the balance over the hook on the nut, and fasten the free end of the wire to the hook of the balance, so that the wire shall be almost or quite straight. Now, by turning the screw, produce a tension of 500 g. This tension of 500 g. will simply straighten the wire, and will be the starting point in all the tests of this experiment. Tap the balance lightly before each reading.

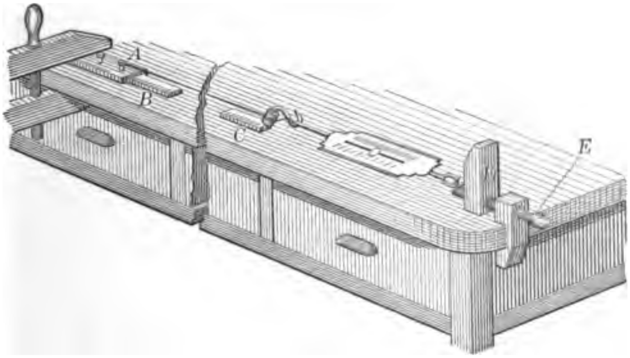


FIG. 16.

b. With pen and ink make a mark on the wire near each end, and as accurately as possible measure the distance between these two marks. Call this distance the length of the wire, as you will be concerned with this portion of the wire only. The gauge number of wire is never accurate. Find the diameter with the micrometer caliper, measuring in several places, and record the smallest measurement. Why the smallest? Lay the meter sticks *A* and *B* under the wire, and, while the wire is stretched as above, adjust them so that the sticks are very close to the wire, and each of the two marks is exactly over one of the large division lines of the scale. See that the wire does not touch the meter sticks, and after final adjustment do not touch either the wire or the sticks. The sticks may be clamped in place if desired.

c. Now, by turning the screw, increase the tension by 500 g. (The balance will then read 1000 g.) Read the position of each ink marker to tenths of a millimeter. The difference between the movements of the two markers is the amount of stretching produced in that portion of the wire between the two markers. Fill in the first three columns of the table below, and *at once* reduce the tension to 500 g., the starting point. Notice whether the wire regains its original length. This will be determined by the position of the markers. If the fastening of the wire at the screw should slip, both the markers would move along equally. This would not affect the accuracy of the work.

d. Make several trials similar to this, increasing the tension by 500 g. at a time (making the balance read 1.5 kg., 2 kg., 2.5 kg., etc.). After each trial reduce the tension to 500 g. Continue in this manner until the wire fails to return to its original length, thus showing that the limit of elasticity has been passed. Save this wire for use in Exp. 17, *l.*

NOTE 1. — In recording the results do not count the force of 500 g. applied to straighten the wire, but call that the real starting point. In reality, somewhat more than 500 g. is necessary to cause the balance to indicate 500 g. when used in a horizontal position, as in this experiment. This is explained in the Appendix, p. 269, but may be entirely neglected here.

e. Record results as follows:

MATERIAL OF WIRE………… LENGTH………… DIAMETER IN MM………… B. & S. SIZE (ABOUT)…………

Tension F	Position of 1st Marker	Position of 2d Marker	Elongation E	$F \times E$	$F \div E$
500 g.			0.0 mm.		
1000					
1500					
etc.					

f. Using the tensions F as ordinates and the elongations E as abscissas, plot the curve on the cross-section paper with a scale of 1 cm. representing 250 g. of force, and 1 cm. representing 0.5 mm. of elongation. (See "Interpretation of Results," pp. xxi–xxv.)

g. From the above results, what is your conclusion as to the relation of the elongation to the stretching force?

h. Measure the wire once more with the micrometer caliper. Is the diameter the same as it was before elongation?

i. *Optional.* To determine Young's Modulus.

References. — Everett's "Physical Constants," pp. 53 and 58; Hall & Bergen, pp. 188–190; Stewart & Gee, Vol. I, pp. 163 and 170.

Explanation. — **Young's Modulus** of elasticity is a constant by means of which the power of a substance, such as steel, to resist elongation is quantitatively expressed. It is the quotient of the longitudinal stress by the longitudinal strain (extension). If a wire of cross-section A sq. cm.

is stretched with a force of F grams, pounds, or dynes, and its length is thus altered from L to $L + E$, the value of Young's Modulus will be $\frac{F \times L}{A \times E}$, since stress $= \frac{F}{A}$ and strain $= \frac{E}{L}$. This will be a very large number, being, in fact, the force in grams, pounds, or dynes necessary to stretch a rod 1 sq. cm. in cross-section to double its length (were that possible without passing the limit of elasticity). In this quotient (Young's Modulus) it is customary to omit all decimals after the first three places, writing the result thus: 2.139×10^{12} (see Appendix, p. 294).

Directions. — Find the area of cross-section in sq. cm. of the wire used and record results as follows:

Length (L) . . . .

Elongation (E) . . . .

Total force used in grams (F) . . . .

or in dynes (F) . . . .

Diameter in cm. . . . .

Area of cross-section in sq. cm. (A) . . . .

Substitute in the formula $M = \frac{F \times L}{A \times E}$ and find

the value of Young's Modulus (M) . . ..

Note 2. — In obtaining Young's Modulus either the total elongation and total tension may be taken, or any tension and its corresponding elongation.

Experiment 15. Elasticity of Extension by Means of the Jolly Balance.

Apparatus. — A Jolly Balance (see Fig. 17), with spiral spring stretching about 5 cm. per gram; weights from one to ten grams.

NOTE 1. — If the **index** or marker consists of a horizontal wire, care must be exercised to see that it is kept strictly horizontal, as when the spring is stretched it untwists somewhat, and different portions of the horizontal wire successively act as the index. If, therefore, the wire be not horizontal, the readings will be proportionately in error. A better plan is to use as an index some sort of a bead or marker on the lower vertical portion of the wire which is in the axis of the coil. Whatever the index may be, either the upper or the lower edge of it should be used in all cases.

NOTE 2. — It is to be observed, as suggested in Note 1, that there is in this experiment a small amount of untwisting of the coil as a whole or flexure of the wire itself; there is, further, a certain amount of torsion or twisting of the wire itself, but both these effects are so small that they are neglected in the work of this experiment.

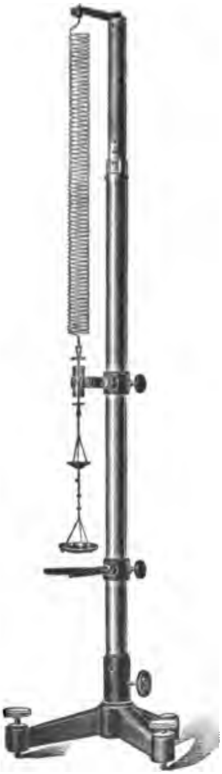


FIG. 17. — Jolly Balance.

Directions. — *a.* Raise the vertical rod supporting the spring until the index is near the top of the mirror scale. Place a load in the pan sufficient to carry it nearly to the bottom of the scale, and level the stand so that the index is directly opposite the vertical middle of the scale, while the spring hangs parallel with the support.

b. Read the position of the index on the scale. As the spring always vibrates somewhat, it is necessary to observe the upper and lower limits of its excursions and take the mean. The eye should be placed in such a position that the index covers its image, in order to avoid parallax. Repeat, and take the mean of these two readings, estimating to tenths of a millimeter.

c. Place a one-gram weight on the pan and read the new position of the index.

d. Repeat, adding one gram at a time until ten readings have been obtained.

e. Remove the load and observe whether the index returns to its original position. Is the spiral spring perfectly elastic within the limits observed? Record results thus:

Load	Reading with Load	Elongation	Elongation per Gram
0 g.		. . . . . .	. . . .
1			
2			
etc.			

f. With a scale of 1 cm. on the paper representing 1 g. of force, and 1 cm. on the paper representing 5 cm. of elongation, plot the loads on the axis of abscissas and the elongations on the axis of ordinates. What is the nature of this "curve"? What does this show as to the relation between stress and strain? This relation is sometimes stated as **Hooke's Law.**

NOTE 3.—The instructions here given apply to the ordinary Jolly Balance. Fig. 17 represents one somewhat different, in which the readings are obtained by a vernier. The above instructions will apply, however, with a few obvious changes. (See footnote, p. iv.)

Experiment 16. Elasticity of Torsion (Twisting).

Apparatus.—A bicycle hub mounted as directed in Appendix, p. 270; rods of brass, steel, copper, etc., about 1 cm. in diameter and somewhat more than 200 cm. long; similar rods of straight-grained wood,—maple, pine, basswood, etc.; two similar rods of maple about 1.5 cm. and 2 cm., respectively, in diameter, or two similar rods of brass about 5 and 8 mm. diameter, respectively; metric weights.

Directions.—*a.* Measure accurately the diameter of the 1 cm. brass rod. Note whether the set screws in the clamp and socket have flat or pointed ends. This will determine whether to measure to the edge or the center of the screws in determining the length of the rod under consideration. (A flat end is preferable.) With the rod in position (see Fig. 18) and a length of 200 cm. between the clamped portions, give the pulley a firm,

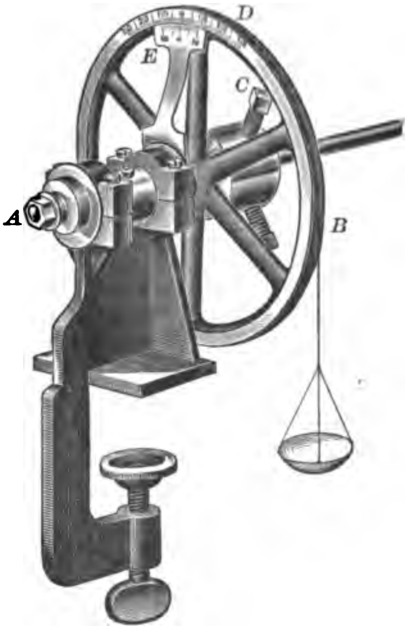


FIG. 18.—Torsion Apparatus.

steady twist in the direction you intend to twist the rod. Allow the rod to return gradually to its position of rest. This is to learn if the apparatus is firmly fastened and to do away with any "slack." Locate the vernier so that its zero line shall coincide with the zero line of the circular scale.

Caution.—Make all changes in the weights in such manner that the rod shall not be allowed to vibrate, nor go beyond the zero position.

b. Place in the scale-pan a weight of 100 g. and note the amount of torsion. Carefully remove the weight *at once* and note whether the scale returns to its zero position. (Be careful that it does not fly past this position.)

c. Repeat *b* with 200, 300 g., etc., up to 1500 g., or until certain that the rod fails to return to the zero position, thus reaching the **limit of elasticity.**

d. Repeat *b* and *c* with different lengths of the rod, say 150, 100, and 50 cm. Use larger weights if necessary to obtain good results.

e. Tabulate results thus:

Diameter of Rod in cm.................. Material of Rod..................

Length of Rod →	200 cm.	150 cm.	100 cm.	50 cm.
Weight	Torsion (in Degrees)			
100 g.				
200				
300				
etc.				

f. With a *constant length of rod* (say 200 cm.) construct a curve showing the relation between the force employed and the amount of torsion. Let 100 g. of force be represented by 1 cm. on the paper on the axis of ordinates, and let 1° of torsion be represented by 1 cm. on the axis of abscissas. From the same origin construct a curve for the 150 cm. length; also one for 100 cm., and one for 50 cm. How do these four curves compare? State the results in the form of a law and call it Law I.

g. With a *constant force* (say 200 g.) construct a curve which shall show the relation between length of rod and amount of torsion, using lengths as ordinates and torsions as abscissas. Using the same origin, repeat with a different force. Repeat with a third force. How do the three curves compare? State the result as Law II.

h. Optional. Repeat the experiment with rods of maple or brass of different diameters, but using only one length, and determine the relation between the amount of torsion and the diameter of the rod. Compare mathematically as well as graphically. See "Interpretation of Results," p. xxi. State the result as Law III.

i. Optional. Repeat the experiment with a steel rod, and construct curves similarly from a common origin, which shall show the relation resistance to torsion of brass and steel. Repeat with rods of other material as desired.

NOTE.—Three or four pieces of this apparatus will be sufficient for a class of twenty pupils if the pupils take turns.

Experiment 17. Tensile Strength of Wires of Various Kinds.

Apparatus. — A Chatillon "yarn tester" (see Appendix, p. 271); a wooden cylinder about 10 cm. long and 2 cm. or more in diameter, with a small hole through its center coincident with a diameter; spring brass wires B. & S. No. 26 and No. 28; piano steel wire, No. 1 or smaller; wires of other metals as desired; a micrometer caliper.

Caution. — A kink in the wire will spoil the experiment.

Directions. — *a.* With the caliper measure the larger brass wire in several places. Call the smallest result the diameter of the wire. Why?

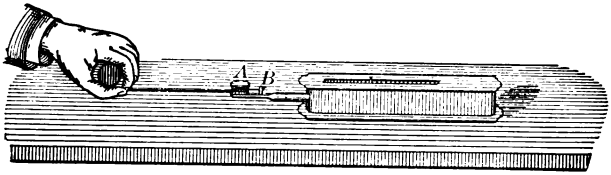


FIG. 19.

b. The breaking strength of the wire is to be determined. Fasten one end of the wire to the balance as directed in the Appendix, p. 271. Pass the other end through the hole in the wooden cylinder, then around this cylinder and through the hole again. If the wire should now be broken, it would doubtless break at one of the fastenings or where it turned a sharp corner, and would not be a fair test. On this account, wind the wire two or three times around each cylinder and see that it is not crossed thereon (see Fig. 19).

c. Now, holding the wooden cylinder in the hand, when sure that the wire draws smoothly and evenly around the curved surface at either end, break it by a steady, rapid pull. Be careful, however, that the pull is not a jerk. Also see that the pull is in line with the balance. Why? Wind the wire around the cylinder as it was when it broke, and see if it was a fair break, as suggested in *b*.

d. Measure the wire again near the break and near the original end. Are the diameters alike in the two places? Was the wire permanently elongated before it broke? How do you know? Repeat twice with *new* pieces of wire. Find the average if the tests agree reasonably well. If not, obtain more and omit those obviously wrong.

e. Weigh a new piece of this wire exactly 10 m. long, and calculate the length of such a piece which would break of its own weight if suspended by one end. Give result in meters.

f. Calculate the tensile strength in pounds of a rod of this material 1 sq. in. in sectional area.

g. Repeat all with a wire of the same material but of a different size.

h. From the results obtained in *a* to *f* calculate the results which should be obtained in *g*, and compare these calculated results with those obtained in *g* by experiment.

i. Repeat *a* to *f* with the piano steel wire.

j. Repeat *a* to *f* with annealed steel wire.

k. Compare results obtained in *f* for the different materials.

l. Find the tensile strength of the piece of wire which you stretched in Exp. 14, of the same size as was used in *a* above.

MECHANICS.

Experiment 18. Center of Mass.

Apparatus. — A piece of cardboard having an area of about 100 or 200 sq. cm.; a plumb line; a pin; a straight-edge or a ruler.

Directions. — *a.* Thrust the pin through the card near one edge, enlarging the hole a little so that the card will swing freely. Suspend the card from the pin driven a short distance into the end of the table-top or other support. From the pin suspend the plumb line in front of the card. When both have come to rest, make a slight pencil mark on the lower edge of the card just back of the plumb line. Remove the card and connect the center of the pin hole and the mark made on the card by a fine straight line. Where is the **center of mass** with respect to this **line of direction?**

b. Repeat *a*, making the hole near an adjacent edge of the card. Where is the center of mass with respect to the two lines of direction?

c. Repeat *a* and *b*, using the other side of the card. Then pierce the card with the pin at one of the intersections to see how the two constructions agree.

d. Thrust the pin up through the intersection of the two lines, and, enlarging the hole a little, hold the pin vertically, point upward, so that the card shall be supported by the head of the pin; or balance the card on the point of a pencil. Observe the position of the card. If it lies horizontal, the center of mass is midway between the two surfaces of the card, in a normal to the lines of direction at their point of intersection.

e. Determine a new line of direction, and notice if it intersects the first two at their common point.

f. Cut off about 10 sq. cm. of the cardboard and relocate the center of mass.

g. What effect has removing material from one side of a mass upon the position of its center of mass?

Experiment 19. Falling Bodies. (*For the Instructor.*)

Apparatus. — An inclined plane (see Appendix, p. 272); a sphere or other body to roll down the plane; a pendulum which audibly beats seconds.

Directions. — *a.* Set the pendulum in motion. Note the position of the sphere when at rest at the top of the plane. Hold it there by a block placed in front of it. Allow the sphere to begin its motion down the plane at the instant one of the ticks occurs, and note carefully, by its striking another block, its position at the following tick. By repetition, find its position at the third and fourth ticks, etc. Repeat several times till satisfied of results. The height of the plane should be such as to permit four or five observations to be taken during the descent of the sphere. Measure the length L and height H of the plane.

b. Measure accurately the space traveled during the first second. Let this be your "unit space." Call this unit space d. Measure the entire space traveled in the first two seconds. How many d's (approximately)? Continue thus to the end of the observations and fill out the second and third columns of the table below to correspond.

c. From the results of *b* compute the distance in *d's* traveled in each individual second, and fill out the fourth column to correspond.

d. What force causes the motion of the sphere? Is practically the same force acting *during* the second second that acted *during* the first? Will this force cause the body to move through the same space (in *d's*) during the second second that it caused it to move through during the first? How many *d's* did the body move through during the first second? How many during the second second? Is it evident, then, that the action of the force during the second second is responsible for but part of the motion during this second second? At the beginning of this second second the body was already in motion; that is, it then possessed a certain velocity. How much of the space traveled during this second second must have been due to the velocity possessed at the beginning of this second? This, then, is called its velocity at that instant; that is, at the beginning of the second second, or the end of the first second. Place this in its proper position in the table.

e. Reasoning as in *d*, what space was covered during the third second? How much of this was due to the force acting during this third second? How much, then, to the velocity at the beginning of the third second, or at the end of the second second? Proceeding thus, fill in column five.

f. Fill in column six as suggested in the table; acceleration, *a*, meaning the increase in velocity during one second.

LENGTH OF THE INCLINED PLANE *L*........................ HEIGHT OF THE PLANE *H*........................

No. of Second, t	**Total Distance Traveled, l**		**Distance Each Second, l'**	**Velocity at End of Each Second, v**	**Acceleration, a**
	in cms.	**in d's**	**in d's**	**in d's**	**in d's**
1					
2					
3					
4					
5					

g. Compare columns one and three (see "Interpretation of Results," p. xxi) and see if you can find any definite relation. State it as Law I. Remember that you are dealing with *d's*, or unit spaces, and in order to have the results appreciated at their true value they must therefore be multiplied by the value of *d*.

h. Compare columns one and four and state Law II.

i. Compare columns one and five and state Law III.

j. Remembering the statement in *g* about multiplying by *d*, state these three Laws as formulæ, thus:

$l =$? $l' =$? $v =$?

k. What peculiarity do you notice about the last column of the table? Will this always be so? What kind of a force causes such a result?

l. Gravity is the constant force we are dealing with here, though its action is interfered with by the plane; that is, gravity is not allowed to have its full effect on the body. But since its effect is lessened uniformly through the whole experiment, the laws here developed will apply to freely falling bodies if the value of d be multiplied by the ratio of the length of the plane to its height $\left(\frac{L}{H}\right)$. This is neglecting the resistance of the atmosphere, friction, inaccuracy of apparatus, etc. This error will be very considerable and will increase as $\frac{L}{H}$ increases; that is, as the inclination of the plane is made less.

m. Represent graphically the relation between l and t^2, using the squares of the times for abscissas, and the total spaces traveled for ordinates.

n. Compare a with the value of l for the first period of time.

Experiment 20. Pendulums.

Apparatus. — A ball of iron or lead 15 to 25 mm. in diameter, with a hole through it, or with an eye, for suspension; a wooden ball about 50 mm. in diameter, similarly prepared; two pieces of thread, or iron wire about No. 34, about 125 cm. long; a meter stick; a clock with a second hand, and beating seconds, or a seconds pendulum connected with a telegraph sounder; a strong bar magnet.

Caution. — If wires are used, do not kink them nor allow any sharp bends in them.

Directions. — *a.* Fasten one of the threads or wires to the iron or lead ball (which will hereafter be called the bob). Suspend the pendulum thus made by slipping the thread into a vertical slit in a wooden peg in such a way that you have a pendulum 50 cm. long, always measuring from the point of suspension to the *middle* of the bob, its center of mass. Or for suspension use the clamp described in the Appendix, p. 272.

NOTE. — Do not suspend the pendulum in such a way that its length will change while it is vibrating. This pendulum represents a **simple pendulum**, though it really is not, as the thread has some weight and the bob some size. All the work of this experiment has to do with **single vibrations**; that is, once through the arc. Once through and back again is called a **complete**, or **double**, vibration. The time required for a single vibration is called the **period**, or **time, t**, of a pendulum. Work independently if you have the use of a second hand on a clock.

TABLE I.

Trial	No. of Vibrations per Minute		
	Iron Ball		Wooden Ball
	Arc 10 cm.	Arc 30 cm.	Arc 30 cm.
1			
2			
3			
Sum			
Mean			

b. Set the pendulum swinging through an arc of about 10 cm. and count the number of single vibrations in a minute. Repeat several times till satisfied that you can observe the results accurately. Then record results of three trials.

c. Repeat *b*, using a larger arc — say 30 cm.

d. Repeat *c*, with the wooden bob and *same* length pendulum.

e. Record results in Table I.

f. How does increasing the length of arc influence the time of vibration?

g. How does changing the weight or material of the bob affect the time of vibration?

h. Using the iron bob and an arc of not more than one-tenth the length of the pendulum, make the proper trials and fill out Table II. Calculate the results in the last three columns.

TABLE II.

Length of Pendulum, l	No. of Vibrations per Minute, n				Time of One Vibration, t	$\sqrt{l}$	$\frac{t}{\sqrt{l}}$
	Trial						
	1	2	3	Mean			
25 cm.							
50							
100							
200							

i. From a consideration of the data of Table II, what relation do you find between the length of a pendulum and its number of vibrations (l and n)? Also express in the form of a proportion, viz., $l : l' = ? : ?$

j. What relation do you find between the length and the period (l and t)? Also express in the form of a proportion.

k. Plot curves showing the relations asked for in *i* and *j*, using the lengths as abscissas.

l. Suspend two pendulums side by side, one 25 cm. in length and the other 100 cm. Set them vibrating together and note result. Does the result seem to verify your conclusion in *j*?

m. All the above work has been with simple pendulums (practically simple). Construct a **compound** pendulum by tying several of the metal bobs on a string, having part of them near the point of suspension, and compare its time of vibration with that of a simple pendulum of the same apparent length.

n. Repeat *b* with one pole of a strong magnet lying on the table just below the iron bob when it is at rest. If one magnet is not strong enough, several may be used with like poles together. They must be within a few millimeters of the bob. Swing the bob through a *very small* arc. The attractive force of the magnet is now added to that of gravity. How does this affect the time of vibration?

o. Repeat *n* with the magnet poles just above the bob. Place them on each side of the suspending thread and have the arc small.

p. Optional. To compute the value of g, use the formula $t = \pi\sqrt{\frac{l}{g}}$. From this $t^2 = \pi^2\frac{l}{g}$, and $g = \frac{\pi^2 l}{t^2}$, in which t means the time of one vibration, and l the length of the pendulum.

Experiment 21. Parallel Forces.

Apparatus. — Two spring balances reading to about 2000 g.; a piece of a meter stick 40 or 50 cm. long; a weight of 2000 g. or less.

Preliminary. — Suspend the balances at the same height, and from them suspend the piece of meter stick in such a way that the balances shall hang parallel to each other (see Fig. 20). Arrange the weight so that it may be moved along the stick at will. Place the weight on the stick, and three parallel forces in the same plane will be represented. As the weight is moved along the stick, the relation between the distances *CE* and *ED*, and the readings of the two balances *A* and *B*, are to be determined.

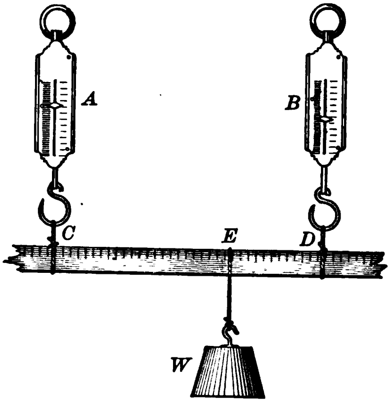


FIG. 20. — Parallel Forces.

Directions. — *a*. With the weight removed read both balances. Call these the "zero positions." Find the weight of *W*.

b. Hang *W* at any point on the stick. Record *CE*, *ED*, *A*, and *B*.

c. Repeat *b* with *W* in a different position, making at least five such trials.

d. Tabulate results thus:

ZERO POSITION OF *A*.................... ZERO POSITION OF *B*....................

WEIGHT OF *W*....................

Trial	*CE*	*ED*	Balance *A*		Balance *B*		Reading of Balance *A* + Balance *B*, *Corrected*
			Reading	Corrected (Reading, minus Zero Position)	Reading	Corrected (Reading, minus Zero Position)	
1							
2							
3							
4							
5							

e. From an inspection of the results determine how the magnitude of the force *W* is related to the sum of the two forces *A* and *B*.

f. Can you see a relation between *CE*, *ED*, *A*, and *B* which is true (approximately) in every case (see "Interpretation of Results," p. xxi).

g. If *A* and *B* are called **component forces**, what shall the force *W* be called? Where would the **resultant** of *A* and *B* be applied?

h. Optional. Add to the above table two columns headed, respectively, $\frac{A}{ED}$ and $\frac{B}{CE}$. Fill out these for each trial. Find the average for each of these two columns and calculate the greatest and least errors. Also calculate the percentage of the greatest and least errors.

Experiment 22. Composition of Concurring Forces.

Apparatus. — Three spring balances reading to about 2000 g.; two pieces of braided linen cord (fish line), one about 60, the other about 30 cm. long; a ruler; a piece of hard wood about 20 × 4 × 2 cm., having a 5 cm. screw hook projecting from a side near one end; a clamp for holding the piece of wood to the table-top; two 5 cm. screw hooks; four small "S" hooks.

NOTE. — If the indices of the balances do not stand at zero when lying with backs on the table, allowances must be made for these displacements in all readings (see Appendix, p. 269).

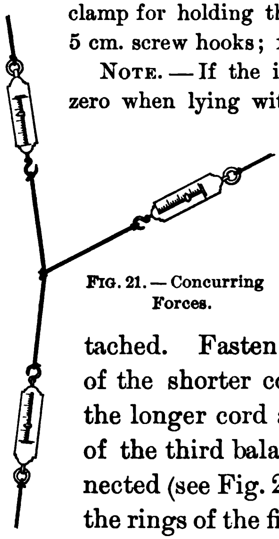


FIG. 21. — Concurring Forces.

Directions. — *a.* Connect the hooks of two of the balances by the longer cord, to each end of which "S" hooks have been attached. Fasten the other two hooks to the ends of the shorter cord, slip one of these hooks over the longer cord and connect the other to the hook of the third balance. Place the balances thus connected (see Fig. 21) backs down on the table, passing the rings of the first two over the two hooks screwed into the top of the table near one edge, about 70 cm. apart. Clamp the piece of wood, with its hook toward the balances, near the opposite edge of the table, in a position such that when the ring of the third balance is placed over it a reading of about 2000 g. will be indicated.

b. Place the center of a piece of cross-section paper on the table-top under the junction of the cords, holding it in place by thumb-tacks or weights. Working always from the same side of the cords, project their ends perpendicularly upon the paper. To do this, place the thick edge of the ruler on the paper and bring one end of it up to each end of the cords, being careful not to push them out of position, and with a sharp-pointed pencil make a mark on the paper directly under the point where the ruler touches the cord. Six points will thus be located. Success in this experiment depends very largely upon the accuracy with which these points are located.

c. Read each balance with great care and record on the paper near it the force indicated.

d. Remove the paper and connect each of the three pairs of points by fine lines. Represent the junction of the lines by *A*, and the direction of the forces by arrowheads. Make all construction lines dotted. Select a convenient scale and lay off from *A* on each of these lines a distance which shall represent the magnitude of the force acting in that direction. Call these distances *AB*, *AC*, and *AD*.

e. Extend any one of these lines, say *AB*, from *A*, an equal distance in the opposite direction, and call its extremity *E*. Connect *E* with *C* and *D*.

f. With reference to *AC* and *AD* what is *AE* called? Why? What is *AB* called? Why? What are *AC* and *AD* called? Why? What figure has been drawn? What part of the figure is *AE*?

g. Repeat *e* and *f*, taking *AC* as the line to be extended. What kind of a figure has been constructed?

h. Clamp the piece of wood in a new position, about 10 cm. either to the right or left of its first position, so that its balance shall register about 1800 g., and with a new sheet of paper repeat *b*, *c*, *d*, *e*, and *f*.

Experiment 23. Lever of the First Class.

Apparatus. — A lever of pine wood 30 × 2.5 × 0.5 cm., with lines across the broad sides 1 cm. apart, the lines on these two sides being exactly opposite each other; a hard-wood triangular prism about 5 cm. long and with faces about 2.5 cm. wide; two wooden blocks to be used as "stops," as shown in Fig. 22, about 5 × 1.5 × 1.5 cm.; two 5-g., two 10-g., and one 20-g. weights; lead chips.

Preliminary. — Arrange the apparatus as shown in Fig. 22, the middle line of the lever resting on the upper edge of the prism. This line of support of the lever, the axis about which the lever tends to turn, is called the **fulcrum** (*F*). If the lever does not balance, place a lead chip on it so that it shall produce equilibrium. The two blocks below the ends of the lever act as **stops** to prevent too great vibration. This lever is in **equilibrium** when it will remain with either end down. Why? The lever being in equilibrium, its weight will in the following work be neglected.

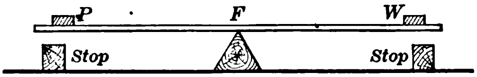


FIG. 22. — Lever of the First Class.

Caution. — Be careful not to change the location of the fulcrum or the lead chip till directed to do so.

Directions. — *a.* Carefully place a 5-g. weight on the right-hand side of the lever, 14 cm. from the fulcrum. Always place the center of the weight exactly over the line. Find by trial what weight must be placed 14 cm. to the left of the fulcrum to produce equilibrium.

b. In this discussion we will for convenience call the force exerted (gravity) on the right of the fulcrum the **weight** (*W*), and the force exerted on the left the **power** (*P*), *a peculiar use of the term power.* Call the distance from the fulcrum to the center of the weight *WF*, the **weight arm,** and the distance from the fulcrum to the power *PF*, the **power arm.**

c. By trial with the lever find the missing terms in columns 2, 3, 4, and 5 of Table I, equilibrium being produced in each case. (In *e* will be found directions for filling out columns 6, 7, and 8.)

TABLE I.

Trial	*P*	*W*	*WF*	*PF*	+ Moment	− Moment	Sum
1		5	14	14			
2	5	10	7				
3		15	12	9			
4	10		4	8			
5	10	15		12			

d. Now change the location of the fulcrum to the line 9 cm. from the right-hand end, and obtain equilibrium as before, except that a much larger lead chip will be necessary. After equilibrium is secured, find as before the missing terms in Table II.

Notice that for the fourth trial two weights are to be used at the *same time*, as indicated. For the fifth trial two weights and two powers are to be used at the *same time.*

TABLE II.

Trial	*P*	*W*	*WF*	*PF*	+ Moment	− Moment	Sum
1	10	10	7				
2	10		8	12			
3		20	8	16			
4	10	10 5	6 8				
5	5 5	10 20		15 21			

e. The **moment of a force** is the tendency of that force to produce rotation about an axis. It is measured by the product of the force by the **force arm** (the force arm is the perpendicular distance from the axis of rotation to the line of direction in which the force acts). For instance, by multiplying *P* by *PF* the moment of the power is obtained. *W* times *WF* will give the moment of the weight.

It will be noticed that *P* and *W* tend to produce rotation about the fulcrum in opposite directions. Call that moment "positive" (+) which tends to produce rotation *with* the hands of a clock, and the other moment "negative" (–). Compute the moments in Tables I and II, placing the algebraic sum of the positive and negative (+ and –) moments in the last column.

f. What does this experiment teach as to the sum of the moments of forces acting on a body in such a manner as to produce equilibrium?

g. What does this experiment teach concerning the power required to balance the weight when the lever has equal arms?

Experiment 24. Lever of the Second Class.

Apparatus. — As in the preceding experiment, and in addition one lever; one prism; two blocks about 10 × 5 × 5 cm.; thread.

Directions. — *a*. Arrange the apparatus as shown in Fig. 23, using a loop of thread to connect the levers. This loop must be of such a length that the two levers shall be horizontal at the same time. Place the thread loop 1 cm. from the end of each lever. The fulcrum *F′* of the lever *CD* is at the middle line; the fulcrum *F* of *AB* for Trials 1 and 2 is at the line 1 cm. from the end. The stops *H* and *I* are located as shown. Since it was learned in the preceding experiment that a force applied downward at *P′* exerts an equal upward force at *D* or at

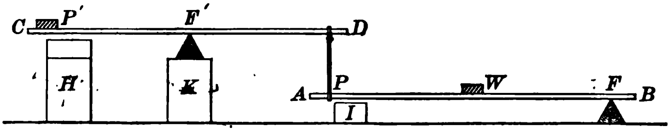


FIG. 23.—Lever of the Second Class.

P, in each of the following tests the power may be considered as applied upward at *P*, although it is actually applied at *P′*. Place lead chips on *CD* at the left of *F′* to produce equilibrium. *AB is the only lever to be considered in this experiment*, and is called a lever of the **second class** because of the relative positions of *P*, *W*, and *F*. *CD* is used merely to enable one to obtain the desired effect on *AB*. Apply a slight downward force at *P′* and notice that this force is transmitted to *AB* through the loop of thread, and acts as an upward force at *P*. The power must actually be applied at *P′* in every case, 14 cm. from *F′* so that $P'F' = F'D$.

b. Proceed as in the last experiment and find the missing terms in the table. In Trials 3 and 4 a readjustment is necessary in order to make *PF* 24 cm. Secure equilibrium as before. Compute the moments and state your conclusions.

Trial	*P*	*W*	*WF*	*PF*	+ Moment	− Moment	Sum
1	5		7	28			
2		10 15	8 4	28			
3		15	8	24			
4	10	20		24			

Experiment 25. Lever of the Third Class.

Apparatus. — As in the last experiment, and in addition a screw hook; a small staple.

Directions. — *a.* Drive the staple through the line nearest the end of one of the levers. Fasten the screw hook to the table-top. Arrange the apparatus by supporting *CD* at its middle line and slipping the staple in *AB* over the screw hook, as shown in Fig. 24. Place the thread loop 7 cm. from *F* on *AB*, and 1 cm. from the end of *CD*. What is now the value of *PF*? Place the apparatus in equilibrium as in Exp. 24. The power is actually to be applied 14 cm. from *F'* on *CD*, this lever serving the same purpose as in the last experiment, and *it is not to enter at all into your calculations.* *AB* is the only lever considered in this experiment, and is called a lever of the **third class** because of the relative positions of *P*, *W*, and *F*. Where is the power applied on *AB*? In what direction? Move the apparatus up and down slightly and see where the fulcrum of *AB* is located. What is the power distance on *AB*? What is the weight distance?

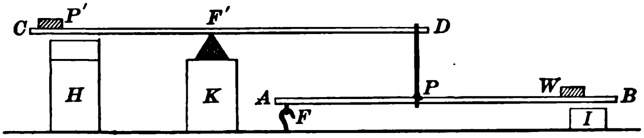


FIG. 24. — Lever of the Third Class.

Trial	*P*	*W*	*WF*	*PF*	+ Moment	— Moment	Sum
1	20	10		7			
2		5	28	7			
3		5 10	22 13	8			
4	15		24	8			

b. Proceed as in Exp. 24 and fill out the above table.

c. From a study of these three experiments with the lever, what relation is found between the power, weight, power arm, and weight arm? State also in the form of a proportion.

d. State what mechanical advantage (intensity or velocity) is gained by the use of each kind of lever, and the ratio of such gain.

e. Give an illustration of each class of levers.

Experiment 26. Influence of the Weight of the Lever.

Apparatus. — A lever; a prism; a balance; weights; a meter stick.

Directions. — *a.* Weigh the lever.

b. Find its center of mass by balancing it on the prism or a knife edge. Mark this location accurately.

c. Place a 20 g. weight on the line nearest one end of the lever, and without the use of any other weights place the lever, so arranged, on the prism in such a position that it shall be in equilibrium. Be sure the fulcrum is exactly at right angles to the lever.

d. Measure carefully the distance from the fulcrum to the center of the weight, and from the fulcrum to the center of mass of the lever.

e. Compute the moment of the weight. The apparatus was in equilibrium; what, then, must have been the moment on the other side of the fulcrum?

f. Suppose the weight of the lever to be the force acting on this other side; how far from the fulcrum must this force be applied to produce equilibrium?

g. Place the results in the following form:

Trial	*W*	Distance *W* to *F*	Weight of Lever	Distance *F* to *c.* of *m.*	Computation as in *f*
1					
2					
3					
4					
5					
etc.					

h. Repeat *c*, *d*, *e*, and *f*, placing the weight on, say, the fourth line from the end.

i. Repeat *h*, using, say, a 50 g. weight.

j. Try other combinations as you choose (a longer lever might be used), and, by comparing the last two columns above, determine whether in every case the weight of the lever has acted as though concentrated at one point. If so, where is that point?

k. Calculate the amount of error and the percentage of error.

l. *Optional.* Suspend a 100 g. weight 5 cm. from one end of a meter stick and a 500 g. weight 5 cm. from the other end. Find the point at which the apparatus will balance. From this work calculate the weight of the stick. Verify by actual weighing.

Experiment 27. The Wheel and Axle.

Apparatus. — Wheel and axle apparatus, as in Fig. 25; an exterior caliper; a meter stick; weight of 1 or 2 kg.; a spring balance, reading to about 2000 g.

Explanation. — The wheel and axle apparatus consists of two or more wheels of different sizes fixed together on the same axis and capable of turning about that axis. Call the larger of two such wheels the **wheel**, and the smaller the **axle**. Arrange the apparatus so that as the cord on one wheel unwinds, that on the other winds up. Have about half the axle cord and nearly all the wheel cord wound upon their respective circumferences.

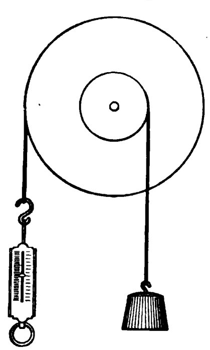


FIG. 25. — Wheel and Axle.

Directions. — *a.* Attach the wheel cord to the hook of the spring balance, and the axle cord to the weight. Slowly raise the weight by pulling vertically downward on the balance. Read to tenths of the smallest division on the balance while the weight is *rising*, and make the proper correction for this position of the balance. How much is this correction (see Appendix, p. 269)?

b. Allow the weight to descend slowly, reading and making correction as before.

c. Repeat *a* and *b* several times and tabulate the results below. The mean of these results will be the **power** necessary to *support* the weight. Call the power P; the weight, W; the diameter of the wheel, D; that of the axle, d; the radius of the wheel, R; that of the axle, r.

Trial	P (*Corrected*)			*W*	*d*	*D*	*r*	*R*	+ Moment	− Moment	Sum
	Up	Down	Mean								
1				. . .	. . .	. . .	. . .	. . .			
2				. . .	. . .	. . .	. . .	. . .			
3				. . .	. . .	. . .	. . .	. . .			
Sum	. .	. . .		. . .	. . .	. . .	. . .	. . .			
Mean	. .	. . .							. . . . . .	. . . . . .	. . . .

d. Measure the diameter of the wheel and that of the axle. Find their ratio. Compare this ratio with the ratio of the weight to the power.

e. Measure with the meter stick the distance *P* moves to raise *W* 10 cm. Compare the ratio of these distances with the ratio of the diameters.

f. Express the relation between *P*, *W*, *D*, and *d* in the form of a proportion. Calculate the percentage of error.

What mechanical advantage, *i.e.*, intensity or velocity, is gained by the use of the wheel and axle?

g. Explain how the wheel and axle can be considered as a continuous lever. Illustrate by a diagram. To which classes may it belong? Compute the moments in the above table.

h. Calculate the amount of work done by *P* in raising *W* 80 cm. Compare this result with the work done in raising *W* the same distance by applying the requisite force directly to it.

i. Change this last result to the corresponding English unit.

Experiment 28. Pulleys.

Apparatus. — Pulleys with very little friction, arranged as in Fig. 26, with the necessary cords; a weight of 1 or 2 kg.; a spring balance reading to about 2000 g.; a meter stick.

Explanation. — The combination of a pulley and its frame is called a **block**. A block may contain one or more pulleys or sheaves. If there are more than one, they are usually of the same size and mounted on the same axis.

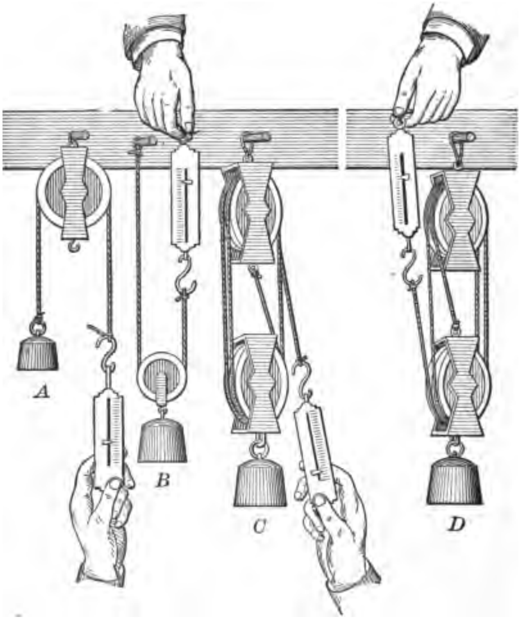


FIG. 26. — Pulleys.

Directions. — *a*. Arrange the apparatus as shown in *A* (Fig. 26). A pulley so arranged is called a **fixed pulley.**

Raise the weight slowly by pulling the balance vertically downward. Record the reading of the balance while the weight is *rising*. Allow the weight to descend slowly and note the balance reading again while the weight is *descending*. What is the balance correction for this position (see Appendix, p. 269)? The average of the power used in raising and lowering the weight is the power required to *support* the weight. Make at least three trials and tabulate the results thus:

Trial	*P*			
	Up	Down	Mean	Corrected
1				
2				
3				
Sum				
Mean				

What is the ratio of *W* to *P*? How far must *P* move to raise *W* 10 cm.? Call the vertical distance that the weight moves *Wd*, and the vertical distance that the power moves *Pd*. What is the ratio of *Pd* to *Wd*? How many sections of the cord are helping to support *W*; that is, how many sections of cord extend upward from *W*?

b. Repeat all of *a* with apparatus arranged as in *B*, noting that the block here forms part of the weight. This arrangement is called a **movable pulley.**

c. Repeat *b* with apparatus as in *C.*

d. Repeat *b* with apparatus as in *D.*

e. Tabulate results as follows:

Part	*P*	*W*	*Wd*	*Pd*	*W* : *P*	*Pd* : *Wd*	No. of Sections of Cord Supporting *W*
A	. . . g.	. . . g.	10 cm.	. . . cm.			
B			10				
C			10				
D			10				

f. Can you discover any relation between *P*, *W*, and the number of sections of the cord supporting *W*, which is true in all cases? This is the **mechanical advantage** of the pulley.

g. Compute the work done by the power in Part *D* in raising *W* 20 cm.; compare this with the work done in raising *W* the same distance by applying the necessary force directly to *W.*

h. Change this last result to English units.

i. Use a diagram and explain how a pulley may be considered a continuous acting lever. Of which class? How do the power and weight arms compare? What mechanical advantage, then, is gained by the use of a fixed pulley? What difference will it make if the diameter of the pulley is changed?

j. How much is the greatest error in *f*? How much is the least error? How much is the greatest percentage of error? How much is the least percentage?

Experiment 29. The Inclined Plane.

Apparatus. — Two smooth boards about 100 cm. long and 20 cm. wide, hinged at *A* (Fig. 27); a small cart or car moving with as little friction as possible; a cord about 30 cm. long; a spring balance reading to about 2000 g.; weights up to 2000 g.; some blocks for supporting one end of the board.

Directions. — *a.* Place the boards on the table with one end of the upper one raised 20 to 30 cm., as in Fig. 27. The board so arranged is called an **inclined plane.** Measure the length *AB* or *EF* of the plane. Call this *L*. Measure the height *BC* of the plane. Call this *H*.

b. Place a weight of about 1 or 2 kg. on the car and weigh the car and its load. Call this weight *W*.

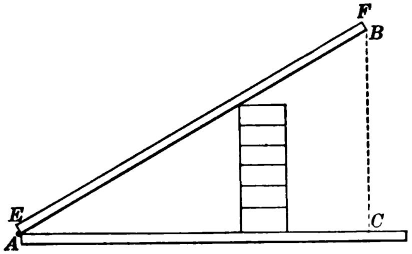


FIG. 27. — Inclined Plane.

c. Attach the spring balance to the car by the cord and note what force applied *parallel* to the plane will move the car slowly and with uniform motion up the plane. Now let the car roll down the plane with uniform motion and at the same rate it ascended. Make three trials. Is a balance correction necessary in this position? Since friction hinders the downward motion (making the balance read too little) to just the extent that it hinders the upward motion (making the balance read too much), the friction may be neglected, and the mean of the "up" and "down" forces will be the power *P* required to support *W* (*at rest*).

d. Record results thus:

W (Weight of Car and Load)......................

L...................... H......................

Trial	1	2	3	Sum	Mean	Corrected
Up						
Down						
Sum	. . .	. . .	. . .	. . . .	. . . .	
General Mean . . . . (Power) =						P..................

Error . . . . % of Error . . . .

e. What is the ratio of P to W? Of H to L? How do these two ratios compare? State the relation between W, L, H, and P in the form of a proportion. State your error and the percentage of error.

f. Repeat the work with a different value for BC and see if the above proportion still holds true.

g. BC will be the vertical rise of the car in passing over the distance EF along the plane. How far would the power move while the weight moves the distance AB? Represent accurately in your notebook the triangle ABC, recording on AB and BC the distances they represent.

h. Calculate the amount of work done by P in moving W along the plane far enough to have risen 20 cm. above the table, and compare this with the amount of work required to lift W upward *vertically* 20 cm.

Experiment 30. Coefficient of Sliding Friction.

Apparatus. — A straight grained board of white pine, about 100 × 25 × 3 cm., with one face as smooth as possible; a cord about 50 cm. long; a spring balance reading to about 2000 g.; weights so that a pressure up to about 10 kg. may be secured; two blocks, one each of pine and oak, about 20 × 10 × 5 cm.; one face and edge of these blocks should be plane and smooth and used *only* for friction. A screw hook is placed in one end of each block.

First Method.

Directions. — *a.* Adjust the board on the table so that it is perfectly horizontal. On the board place the pine block with the face side down. Load it with weights until the total pressure P (including the weight of the block) is about 1000 g. Attach the balance to the screw hook, by the cord, and, keeping the cord horizontal and the grain of the block parallel to that of the board, cause the block to slide along the board with uniform motion. Is the force necessary to start the block greater than that required to keep it in motion? Why? The **friction,** or resistance to motion, is equal to the force F required to keep the block in motion. How much, then, is the friction in this case? Is a balance correction necessary? Try to maintain a slow, uniform motion of the block as you pull it along the board. The force necessary to do this will probably vary at different points. Friction under the best of conditions is irregular, and it will not be at all surprising if the index of the balance vibrates somewhat as the block is moved. Observe at least five readings of the balance for each journey of the block. Take the mean of these five readings, repeat several times and record the is shown from the consideration of the forces acting on a mass located on an incline. The weight of the mass M on the incline may be resolved into the two forces P and F, the respective functions of which are to produce pressure against and motion along the plane; hence, from definition, $\frac{F}{P}$ represents the C. of F., but since the triangle DPW or DFW is similar to ABC, then $\frac{BC}{AC}$ also measures the C. of F.

q. Try the oak block.

r. How do the results obtained by this method compare with those obtained by the first?

MECHANICS OF FLUIDS.

Experiment 31. Weight of Air. (*For the Instructor.*)

Apparatus. — An air pump with a pressure gauge; a bottle with heavy walls with a capacity of about two liters, fitted with a rubber stopper through which passes a strong glass tube having on its outer end a short piece of rubber tubing; a pinchcock for *tightly* closing the rubber tube; a balance; weights.

NOTE 1. — A metallic sphere with a stopcock is often used in place of the bottle and its connections. Whichever one is used, it should have its volume determined once for all and marked upon it. This may be learned from the weight of water it will contain. A good arrangement for the **pressure gauge** is a straight glass tube nearly a meter in length dipping into a vessel of mercury. Connect the top of the tube to one arm of a three-way tube having attached to its other arms the bottle and the air pump, respectively. Place a meter stick beside the tube, and the gauge is complete.

Directions. — *a.* Counterpoise the bottle and its connections with sand or other material.

b. Connect the bottle with the air pump, being careful to have all the joints clean and tight. It may be necessary to use vaseline or glycerine for this purpose. Exhaust a portion of the air from the bottle. Close the rubber tube tightly with the pinchcock and note the reading of the pressure gauge. If the mercury column remains at rest, it is evident that the work has been done satisfactorily; if not, the joints must be looked after farther and made tight.

c. When satisfactory, read the height of the barometer (see Exp. 32, *c*) and note the temperature by the thermometer attached to the barometer case. Disconnect the bottle from the pump and replace it on the balance. See if the balance is now in equilibrium. If not, find what weight must be added to produce equilibrium. Is this the weight of the air removed? Open the pinchcock and listen. What causes the sound?

d. Was all the air removed from the bottle? To answer this question, compare the reading of the pressure gauge with that of the barometer at the time of the experiment. If all the air had been removed, what would have been the reading of the gauge? What did it actually read? What portion, then, of the air in the bottle was removed?

e. From your results calculate the weight of 1 cc. of air in grams, keeping five decimal places.

NOTE 2.—If you compare your result with that given in the Appendix, p. 287, you will find quite a discrepancy. Much of this is due to the fact that all such tables are calculated on the plan of the work being done under **standard conditions,** which are at the temperature of melting ice (32° F., or 0° C.) and when the barometer registers 760 mm. (29.922 inches) in height. This will necessitate two corrections in the work.

FIRST CORRECTION.—If the work is done at a *higher* temperature than the standard, it is evident that the air will be expanded, and therefore not so much of it in a given volume (in the bottle) as there would be under standard conditions. This will cause the result in *e* to be less than it would be under standard conditions. Correction for this (to find the volume at 0° C.) may be made as follows: A given mass of air at 0° C. has a certain volume. If its temperature now be raised, its volume will be increased by $\frac{1}{273}$ of its volume at 0° for every such degree of increase in temperature, and therefore the given volume will contain a proportionally less mass of air.

Second Correction. — A correction must be made for barometric height as follows: It is a fact that if the barometric height were *twice* as great as it is, your result (the weight of 1 cc. of air) would likewise be twice as great as it is; that is, if you obtain 0.00120 g. as the weight of 1 cc. of air when the barometer reads 740 mm., you would have obtained 0.00240 g. as the weight of 1 cc. if the barometer had read 1480 mm. To find what 1 cc. would have weighed if the barometer had read 760 mm. (the standard), increase the weight found (0.00120 g.) by $\frac{20}{740}$ of itself.

These corrections for temperature and pressure may be understood from the following example:

Volume of flask, 1740 cc.
Weight of air exhausted, 1.82 g.
Height of barometer, 29.25 in.
Reading of pressure gauge, 28.25 in.
Temperature, 72° F.

Corrected height of the barometer, 29.26 in.

Fraction of air exhausted, $\frac{28.25}{29.26} = 0.9655$.

Volume of air exhausted, 1740 cc. × 0.9655 = 1680 cc.

1680 cc. of air weighed 1.82 g.; therefore, 1 cc. of air weighs 0.001083 g. at 72° F. and 29.26 in. (height of barometer).

72° F. = 22.2° C. ($40° \times \frac{5}{9}$).

1 cc. of air at 22.2° C. will become 0.925 cc. at 0° C.

1 cc. at 22.2° C. (0.925 cc. at 0° C.) weighed 0.001083 g.

1 cc. at 0° C. therefore weighs 0.00117 g. (barometer, 29.26 in.).

1 cc. at 0° C. and 29.922 in. (standard conditions) would weigh $\frac{29.922}{29.26}$ of 0.00117 g., or 0.00123 g. *Ans.*

Note 3. — If it is desired to find the weight of any other gas, as ordinary illuminating gas, it may be done by connecting the bottle after exhaustion to the gas supply pipe and allowing it to fill with this gas instead of air. The gas pipe should be opened previously for a moment, to dispose of any air therein, and the pinchcock should be left open for a moment after removing the bottle from the pipe, as the gas is delivered under a slight pressure.

Experiment 32. The Barometer.

Apparatus. — A bottle with a two-hole rubber stopper containing a glass tube in one hole and a plug or glass rod in the other; a Y-tube of brass, lead or glass connected to two glass tubes *differing* in diameter, but about equal in length (about 100 cm.); a short piece of rubber tubing is placed on the free end of the Y-tube to be closed by a pinchcock (see Fig. 29); two vessels of water; a barometer.

Preliminary Directions. — *a.* Fill the bottle with water. Press in the stopper, taking care that the bottle and the tube are completely filled with water. The apparatus must be air-tight. Attempt to suck water out through the tube. Do you find that there is or is not such a force as "suction"? Decide this question before proceeding further. Remove the plug from the second hole of the stopper and try again. What force caused the water to flow from the bottle in the second trial? What prevented this in the first trial?

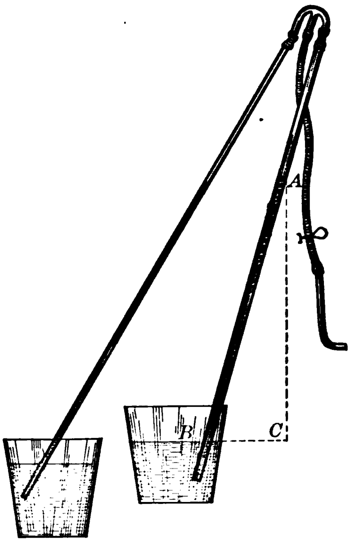


FIG. 29.

b. With the pinchcock removed introduce the two glass tubes into the vessels of water, as in Fig. 29. Note the height to which the water rises in each tube on account of capillarity. "Suck" most of the air out through the rubber tube and close it with the pinchcock. What causes the water to rise in the glass tubes? Compare the levels of the liquid in the two tubes, making proper correction for capillarity. Incline the two tubes at *different* angles. To do this it may be necessary to have them dip in separate vessels of water. With the tubes so inclined: (1) Measure the length of the column of water *AB* along *each* tube *above* the surface of the water in the vessel; (2) measure the *vertical* distance *AC* from the top of the column of water in each tube to the water surface in the vessel in which the tube dips; (3) repeat (1) with one vessel higher than the other; (4) repeat (2) with one vessel higher than the other. Show by diagram each of these measurements.

Is there a close agreement in the two measurements in (1)? in (2)? in (3)? in (4)? **Be careful hereafter to measure vertically in all similar work.** Are the two tubes of the same diameter? How high would the water stand in the tubes if they were each 1 sq. cm. in area? 1 sq. in.? 1 sq. ft.? What difference does the size of the tube make in the height of the column of water?

Directions. — *c.* Read the barometer. Do this as follows:

1) Read the temperature as shown by the thermometer (corrected if necessary) which is attached to the barometer case. Do this at once, before the heat from your body has had time to affect the instrument. Before proceeding further, see that the barometer hangs *vertically*, entirely free at the bottom.

2) Carefully adjust the mercury level in the cistern at the bottom. To do this, first shake the cistern *gently*, in

order to detach the mercury surfaces from their contact with the glass, then turn the thumbscrew at the bottom of the instrument, alternately lowering and raising the surface of the mercury in the cistern, till finally satisfied that it just touches the ivory point which projects downward from the cover of the cistern. This is the case when light is just cut off between the point and the mercury surface. This ivory point is the zero of the barometer scale from which all measurements are made. Always finish this adjustment with an upward motion of the mercury.

3) Tap the barometer lightly with the finger near the upper mercury surface to overcome the adhesion between the mercury and the glass.

4) Set the vernier so that the bottom of it (its zero line) is apparently tangent to the convex surface of the mercury in the tube. When thus set, the background will be visible through the tube at the edges, while light is barely cut off in the middle. Avoid parallax (see Exp. 1, Note).

5) Read the vernier as directed in Exp. 2. Remember that the "height of the barometer" is the distance from the mercury surface in the cistern below (the zero point of the instrument) to the mercury surface in the tube above (the zero line of the vernier). This distance is read directly from the scale, which is a part of the instrument, though, as the upper part of the scale is the only portion of it that is ever used, the lower part is always omitted.

6) Begin again with (1) and compare the new reading with the first one. Repeat till three successive readings agree.

d. Corrections to be made to the observed reading of the barometer:

1) Every barometer has an **instrumental error** peculiar to itself, which may be due to various causes. This correction should be ascertained once for all and posted close by the instrument.[1] It should include corrections for capillarity and for imperfect vacuum, as well as for the instrumental error proper. If the latitude of the place is far from 45°, which is accepted as the standard, another correction for latitude is necessary and should be included in the instrumental error. This is due to the change in the force of gravity caused by the shape of the earth. It may be considered as 0.01 in. for every 4° of latitude. A good treatment of this subject may be found in "Barometers and the Measurement of Atmospheric Pressure," mentioned below.

2) A correction must be made for temperature, as an increase in temperature causes an unequal increase in the volumes of the mercury and of the scale outside. It would be well to have a table of temperature corrections posted by the instrument; however, it is true, in general, that at a temperature of 50° F. the height of the mercury column of the barometer must be corrected by subtracting from it $\frac{1}{518}$ (0.00193) of its length; at a temperature of 60°, 0.00283 of its length; at 70°, 0.00373; at 80°, 0.00463; at 90°, 0.00553; at 100°, 0.00643. This temperature correction includes both the mercury and the scale correction, the scale (barometer case) being made of brass. (See Stewart & Gee, Vol. I, p. 207; or, better, "Barometers and the Measurement of Atmospheric Pressure," 1894, U. S. Weather Bureau, Washington, D. C. This latter contains an elaborate table of temperature corrections.)

3) For purposes of comparison all barometer readings are corrected as above, and in addition a further correction for elevation must be made, in order to reduce all readings to the sea level. This correction varies with the temperature of out-of-door air and should

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[1] The "instrumental error" may be ascertained by comparison with a standard barometer. The U. S. Weather Bureau will make this comparison free of charge.

be obtained from tables (see "Instructions to Voluntary Observers," issued by the Weather Bureau, 1892). It is about 0.01 in. for each nine feet of elevation. Tables of such corrections for elevation and temperature combined should be placed convenient of access to the pupils.

e. What force is it that holds the mercury to this height in the barometer? What change would it make in the height of the column if the area of the cross-section were 1 sq. cm.? What would be the volume of such a column? What would be the weight of a column of this size if mercury weighs 13.6 times as much as water? Is this the pressure of the atmosphere on each sq. cm.? How high would the barometer column be at the present time if it were composed of water instead of mercury?

f. From the observed reading of the barometer calculate as in *e*, and state the present atmospheric pressure in:

	Inches of Mercury	Mm. of Mercury	Feet of Water	Pounds per sq. in.	Grams per sq. cm.	Dynes per sq. cm.
Observed						
Theoretical		Fill out	this line as	per directio	ns in *g*	

g. Is the pressure as above calculated the same at all places? Is it always the same at any one place? If the force of gravity be the same as at the sea level at Paris, and the atmospheric pressure be sufficient to sustain a column of mercury 760 mm. in height at a temperature of 32° F. or 0° C., this is called a pressure of **one atmosphere** and is the scientific **standard of pressure.** Supposing this to be the case, fill out the "Theoretical" line of the above form, using as a basis a pressure of 760 mm. of mercury (third column of the table).

NOTE.—In this experiment the barometric height is considered in inches instead of millimeters, because in the extensive use of the instrument by the Weather Bureau of this country the English method of graduation is used.

Experiment 33. Water Pumps.

Apparatus. — A lifting pump; a force pump with an air chamber; water.

Caution.—Pumps for laboratory use are necessarily of glass in part, so that the action of the valves may be seen. This being the case, they should be handled very carefully.

Directions. — *a.* Begin with the lifting pump. Work it carefully, noting the position of the valves continually. If the motion of the valves is not noticeable at first, increase somewhat the suddenness of the stroke, but still carefully. How many valves are there? When the piston descends, what prevents the water in the pump from going back into the cistern? Make a sketch showing the position of each of the valves during the *up* stroke of the piston and name the sketch. Make another showing their position during the *down* stroke.

b. What causes the water to move from the cistern below, up through the lower valve? How high could this valve be placed to-day, theoretically, and the pump still work? How high at the time of doing Exp. 32? How high to-day if mercury were used instead of water? Can it be placed as high as this in practice? Why?

c. What force causes the water to move from its position above the lower valve to its position above the upper valve? What force causes it to move from this position into the receiving vessel? Must the upper valve, when at its lowest position, also be within the height limit as determined for the lower valve in *b*?

d. Is the force of gravity of much or little assistance in *b* above? Explain.

e. Can you suggest any way by which, with such a lifting pump, the water might be raised two or three times as high as stated in *b*, or even higher?

f. Examine the force pump as in *a* and *b* above.

g. Though the piston is actually pushing out the water only about one-half of the time, the stream itself is quite regular and even. Explain fully.

h. Evidently water could be *forced* in this manner to a considerable height. The height, however, would be limited in practice. What two factors would be most prominent in determining this limitation?

NOTE. — The steam fire engine is simply a force pump or, rather, a combination of two force pumps, worked by steam instead of by hand power, and so connected that when one piston is going up the other is going down, thus tending to keep the stream of water more nearly constant.

Rotary pumps are occasionally met with working somewhat similarly to two gear wheels, with spaces between the teeth which are filled with water. The wheels then revolving push the water on ahead. *Centrifugal pumps* are arranged to take in water at the axis and by their rapid revolution force it out at the circumference.

Experiment 34. The Siphon.

Apparatus. — A large vessel of water (a battery jar will answer); a smaller vessel with a capacity of about 400 or 500 cc.; a graduate; a rubber tube about 40 cm. long; a siphon consisting of a glass U-tube with parallel arms separated a distance of about 8 cm., the arms being about 6 or 7 cm. longer than the depth of the large vessel mentioned above (the diameter of the tube is not important, but one end should be partially closed if necessary by simple heating, so that in *d* below only about 300 cc. of water will flow); very short piece of rubber tubing to fit glass tube.

Directions. — Fill the rubber tube with water. Close the ends and place one end in the vessel of water and below the surface. Open this end of the **siphon,** still keeping the other end closed.

a. With the closed end lower than the surface of the water in the vessel, is the downward pressure of the water at this end greater or less than the atmospheric pressure (upward)? (As a help on this question, consider whether the atmospheric pressure is the same in all directions at a given point.) After you have formed your opinion open the tube and see if your judgment was correct. It may be well first to place a vessel to catch any water which *might* run over.

b. Repeat *a*, holding the closed end higher than the surface of the water in the vessel. Ask yourself the same question and test your judgment in the same manner.

c. With water in the two vessels and at the same level connect them with a siphon filled with water. Now slightly raise one vessel and allow water to flow from it to the other vessel through the siphon. Can a liquid in this manner be finally left at a higher level than that from which it comes?

d. Place one end of the glass siphon in the water in the large vessel so that its "short arm" shall be 10 cm. long. Measure carefully this length, which is the distance *vertically* from the highest point of the tube to the surface of the water. Keep this length constant as the surface of the water in the vessel is lowered. This may be readily accomplished by marking the proper position on the tube by a piece of rubber tubing. Always place the longer portion of the glass siphon outside of the jar. Start the siphon by "suction" and measure in the graduate the water which flows in a minute. Determine the difference between the lengths of the short and the long arms. The length of the "long arm" is the distance from the highest point of the siphon to the end of the arm which is outside of the vessel. If the long arm also dips in a liquid, its length is to be determined in the same way as that of the short arm.

e. Repeat *d* with the short arm 15 cm. in length, then in succession, 20, 25, 30, 40, 45 cm., and place the results in tabular form, as follows:

NO. OF SIPHON................ DIAMETER IN SMALLEST PART................

Time	Length of Short Arm	Length of Long Arm	Difference in Lengths of Arms	Volume of Water Flowing in 1 Min.
1 min.	5 cm.			
1	10			
1	etc.			

f. What force causes the water in the long arm to fall? You learned in Exp. 32 that there was no such force as "suction." What causes the water to rise in the short arm? The force of gravity is intimately connected with this latter action. Explain how.

g. There is a limit to the length of the short arm. Consult the barometer and see what this limit would be at the present time if mercury were used in place of water. By calculation determine what it would be if water were used. How long could the short arm have been at the time of doing Exp. 32?

h. From a consideration of *e* above, what is found to be the general relation between the differences in the lengths of the two arms and the rates of flow? (Note that the *difference* is asked for.)

i. Plot the curve for the results, using as ordinates the differences in the lengths of the two arms, and as abscissas the corresponding rates of flow. After laying out the curve, determine by inspection of it the rate of flow corresponding to a short arm 35 cm. long. (First find the ordinate corresponding to the necessary difference in length of the two arms.)

j. Test this calculation by experiment.

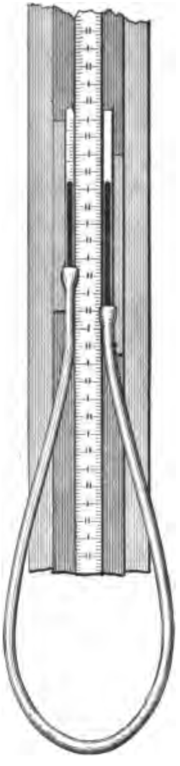

FIG. 30. — Boyle's Law Apparatus.

Experiment 35. Boyle's Law.

First Method. (For the Instructor.)

Apparatus. — Boyle's Law Apparatus, as in Fig. 30 (see Appendix, p. 273); a barometer.

Caution. — Do not warm by the breath, the hand, or in any other way the closed tube. Do not touch that tube at all (see Caution, p. 285).

Directions. — *a.* Clamp the two slides near the bottom of the apparatus, after having brought the mercury surfaces in the two tubes to the same horizontal level. Observe the height (in mm.) of the mercury in both tubes above the zero of the scale and record in columns A and B of the table below. Record in column V the volume of the air confined in the closed tube. Raise the slide carrying the closed tube, and clamp it in successive positions, recording the heights (in mm.) of the two mercury surfaces and the corresponding air volumes for at least five positions. Now return this slide to its former position (where the mercury stood at the same level in each tube) and clamp it fast. Raise the slide carrying the open tube, by successive adjustments of about 10 cm. each, until the limit of the apparatus has been reached, recording the height of the mercury in each tube for every adjustment, as well as the corresponding volume of air within the closed tube. (See Fig. 30.)

HEIGHT OF THE BAROMETER H......................in. = ...mm.

	A	B	C	P	V	$P \times V$
Reading	Height of Mercury in Closed Tube	Height of Mercury in Open Tube	$B - A$	Pressure (Height of Barometer in mm. plus Readings in Column C)	Volume of Air in Closed Tube (in cc.)	
1						
2		Here will	be reco	rded about 20 read	ings.	
etc.						

By computation from columns *A*, *B*, and *V* find the corresponding values for *C*, *P*, and $P \times V$.

b. When the mercury stands at the same level in both tubes, how does the pressure, density, and elastic force of the confined air compare with that of the air outside? Why?

c. In the third reading, when the mercury in the closed tube is higher than that in the open tube, how much is the pressure, density, and elastic force of the confined air? Why?

d. In the tenth reading, when the mercury in the closed tube is lower than that in the open tube, how much is the pressure, density, and elastic force of the confined air? Why?

NOTE 2. — *P* and *V* represent respectively the *total* pressure and the volume of the air confined in the closed tube. If a gas analysis tube be used, the actual volume in cc. of the confined air will be known, whatever be the position of the tube. If other than a gas analysis tube be used for the closed tube, let 1 cm. of the length of this tube be taken as the unit volume. The volume of air in this tube will then be measured by the length of this air column in centimeters.

e. Plot a curve, using volumes for ordinates and pressures for abscissas. What kind of a curve is obtained?

f. What relation is shown in this experiment between the volume of a gas and the pressure upon it?

Second Method. (For the Pupil.)

Apparatus. — A glass tube about 50 cm. long with a bore of 1 mm. or a little less. One end of the tube is sealed and a volume of air is enclosed by a column of mercury about 15 cm. long; the lengths of the tube, air, and mercury columns should be in about the proportions given in Fig. 31.

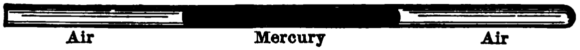

FIG. 31.

NOTE 3. — The mercury may be placed in the tube in various ways. *First,* by means of a glass funnel attached to the tube by a short piece of rubber tubing. *Second,* by heating the tube strongly and then allowing it to cool while the open end dips in a vessel of mercury. *Third,* by allowing the open end to dip in a vessel of mercury placed under the receiver of an air pump and exhausting as much of the air as may be necessary.

By means of an iron wire the mercury may be located in any part of the tube as desired.

In measuring the length of the air column allowance must be made for the narrowed portion of the tube at the closed end, unless the curve there agrees closely with that of the mercury surface.

Caution. — Handle the tube entirely by the open end. Be careful that the mercury and the air in the tube at the closed end do not have their temperature changed in any way during the experiment. Be careful, too, not to jar the tube or in any way break the column of mercury. If it does become broken, ask help of the instructor.

Directions. — *a.* How much is the atmospheric pressure at the present time? State the answer in mm. of mercury (see Exp. 32, *f*). In what direction is this pressure exerted? Lay the tube on the table so that it is horizontal. Measure the lengths of the enclosed air and mercury columns to tenths of a mm. How much is the pressure on the surface of the mercury which is in contact with the enclosed column of air? How much is the tension or pressure of the enclosed air as compared with that of the air outside?

b. Hold the tube vertically with the open end upward, alongside a meter stick and measure the length of the enclosed air column. To what pressure is the enclosed air now subjected?

c. Carefully turn the tube upside down. Why does not the mercury run out? Measure the length of the enclosed air column. How much is the pressure of the enclosed air now?

d. Read the barometer and calculate (in mm. of mercury) the pressure on the enclosed air in *a*, *b*, and *c*, respectively.

e. Enter results thus:

HEIGHT OF BAROMETER.................. CORRECTED HEIGHT..................

Length (Volume) of Air Column in	Pressure Corresponding to this Volume (Length)	Product of Volume and Pressure
a. Horizontal Position........... mm.	.... mm. of Mercury	
b. Vertical Position ; Open End Up. .... mm.	.... mm. of Mercury	
c. Vertical Position ; Open End Down. .... mm.	.... mm. of Mercury	

f. Are the products of volumes and pressures nearly equal? When two sets of results thus multiplied together give equal products (approximately), in what proportion are the two sets of results? What do you find to be the relation between volume and pressure of a gas at *constant temperature?*

g. Let H represent the height of the barometer at the time the above data were obtained, p the length of the mercury column, and v and v' the volumes corresponding to the positions in *b* and *c*. Then from the above law (*f*) we may state

$$(H + p)\, v = (H - p)\, v'.$$

Substitute the values found for p, v, and v' and compute the value of H. How does this calculated value compare with the observed value? How much is the error? How much is the percentage of error?

Experiment 36. Transmission of Liquid Pressure.

First Method.

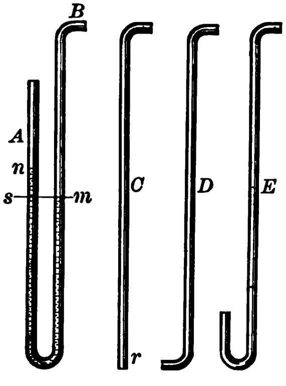

FIG. 32.

Apparatus. — A glass U-tube, as shown at *AB* (Fig. 32), about 25 cm. high and about 5 mm. internal diameter, bent so that the two arms are about 1 cm. apart; three glass tubes bent as shown at *C*, *D*, and *E*, each about 30 cm. in length and 5 mm. internal diameter, the tops bent as shown, to prevent kinks in the rubber connecting tube; about a foot of rubber tubing to fit the glass tubes; a battery jar; water; a piece of meter stick about 30 cm. long.

NOTE. — The U-tube should be attached by rubber bands to the piece of a meter stick, and both should be attached in the same manner to the outside of the jar of water. This will leave the hands free for other work. See that the tube *AB* is kept vertical at all times (see Exp. 32 *b*). Each of the tubes should be thoroughly wet inside before beginning *a*. See that there are *no air bubbles in the tubes* during the experiment.

Directions. — *a.* Nearly fill the battery jar with water. Insert the lower end of the tube C and measure the difference of liquid levels inside and outside of the tube, due to capillarity. Repeat with D and E.

b. Half fill the U-tube with water. Connect the arm B with the upper end of the tube C by means of the rubber tube. The water in the U-tube serves as a pressure gauge.

c. Place the lower end of C in the water in the jar at such a depth that the liquid pressure exerted upward at r, and transmitted through the rubber tubing, shall depress the surface at m and raise that at n, until the difference of their levels, sn, is 1 cm. Measure the depth of the liquid surface inside of C below the surface of the liquid in the jar. Correct this measurement for capillarity by adding the difference of liquid levels found in *a.* Why is this correction to be *added?*

d. Sink the tube C to a greater depth, until sn becomes 2 cm., 3 cm., etc., to the limit of the jar. Measure the depth of the liquid surface inside of C below the surface of the water in the jar each time and correct for capillarity.

e. Repeat *c* and *d* with tube D in place of C, but have D about half immersed in the water at the time of connecting it with B by the rubber tube. More or less of the water then in the tube will be driven out of it as the rubber tube passes over D. The same precaution must be observed in using tube E.

f. Repeat *c* and *d*, using tube E in place of C.

g. Attach C once more. Close the rubber tube with the fingers and lower C into the water. Release the hold on the rubber tube. Repeat with *D* and *E*. In what direction was the water moving as it entered the lower end of *C*? In what direction, therefore, was pressure exerted by the water in the jar? In what direction was this pressure exerted when *D* was attached? when *E* was attached?

h. Record results in the following table:

Gauge Reading	Difference of Levels with *C*	Difference of Levels with *D*	Difference of Levels with *E*
1 cm.			
2 cm.			
etc.			

i. From the tabulated results compare the liquid pressures transmitted in different directions at the same depth below the surface.

j. From results found in *d*, what do you conclude about pressure at different depths?

Second Method.

Apparatus. — An Argand lamp chimney; a card to cover the end of the chimney; a glass tumbler; a battery jar of water; a second Argand lamp chimney fitted at the large end with a solid rubber stopper, at the small end with a three-hole rubber stopper in which are inserted three glass tubes of equal internal diameters terminating inside as shown in Fig. 33. The centers of the lower ends of these tubes must be at the same level.

Directions. — *a.* Put the card on one end of the open chimney and, holding it in place with one hand, push that end down into the jar of water. Remove the hand from the card. Result? Move the chimney around until certain of results. Now pour about half the tumblerful of water into the chimney, first pushing the chimney to the bottom of the jar. Then slowly lift the chimney. Record the height of the water inside the chimney when the card floats away. What determines the force which held the card against the chimney?

b. See that the chimney containing the three tubes (Fig. 33) is full of water, *with no air bubbles in the tubes.* Holding the chimney vertically, press against the rubber stopper at the bottom. Note the height to which the water is pushed in each of the three tubes. Repeat until certain of results. If the three tubes differ in diameter, allowance must be made for capillarity.

c. In what directions did the water move in entering the tubes? What fact does this show in regard to the transmission of pressure by liquids (water being taken as a type of all liquids)?

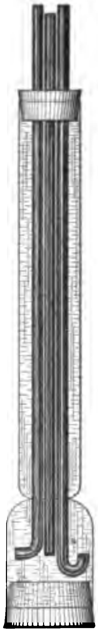
FIG. 33.

Experiment 37. Archimedes's Principle.

Apparatus. — A metal cylinder (or a sphere); thread; a tumbler or a beaker; clean water; a vernier caliper; a balance; weights.

Directions. — *a.* Find the diameter of the cylinder in centimeters and compute its volume, as in Exp. 1. What volume of water would it displace if placed in the beaker of water? Allowing 1 cc. of water to weigh 1 g. (see Exp. 6), what would this displaced water weigh?

b. Weigh the cylinder with a thread attached ready to be used as in Fig. 34.

c. Suspend it by a thread from the hook of the balance beam and weigh it again when entirely immersed in water (see Fig. 34). Of course the tumbler containing the water must not stand upon the scale-pan. See, too, that the cylinder does not touch the side of the beaker. Avoid air bubbles clinging to the cylinder under water.

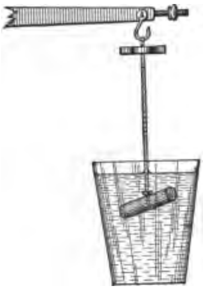

FIG. 34.

d. How do the weights in *b* and *c* compare? What do you think causes this?

e. How much weight does the cylinder seem to lose when suspended in water? Does it actually lose weight? Compare this apparent loss of weight of the cylinder with the weight of the water displaced by it when immersed in water (see *a* above).

f. If the weights referred to in the last sentence of *e* should be found by very careful experiment to be exactly like each other (to have the same value), a law could be determined. State it. This law is called **Archimedes's Principle.**

Experiment 38. Law of Floating Bodies.

Apparatus. — A wooden bar 25 cm. long and 1 cm. square, loaded with lead sufficient to give it a vertical position when floating in water; a hydrometer jar tall enough to contain the bar; water; a balance with weights.

NOTE. — One face of the wooden bar contains a mm. scale with the zero at the loaded end. The bar should be made of pine or other light wood. After being loaded with melted lead or shot, the remaining portion of the hole should be filled with putty, and the bar soaked in hot paraffine, to make it impervious to most liquids. For the purpose of this experiment the bar should be considered to be made entirely of wood. Pay no attention to the fact that it contains the lead.

Directions. — *a.* Find the weight of the bar in grams.

b. Ascertain what length of it is submerged when floating in water, as in Fig. 35. As the water rises around the bar because of capillarity, this observation may best be made by looking at the stick from just below the surface of the water, as shown in Fig. 35. What is the volume of the submerged portion?

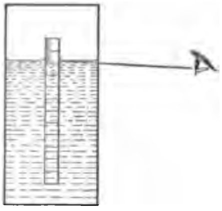

FIG. 35.

c. How does the volume of the submerged portion compare with the volume of the water displaced by it?

d. Remembering the weight of 1 cc. of water, what is the weight of the displaced water?

e. Compare the weights in *a* and *d.* May any difference be readily accounted for by unavoidable errors of observation, etc.?

f. Place a 1 g. weight on the top of the bar. What is the weight of the water now displaced? Repeat with 2 g., 3 g., etc.

g. What weight of water does a floating body displace?

SPECIFIC GRAVITY.

Experiment 39. Density Determined by Means of Weight and Volume.

First Part — Density of Water.

Directions. — *a.* What is the weight (mass) in grams of 1 cc. of water? (See Exp. 6, *i.* If the results there obtained were not thoroughly comprehended at the time, repeat the work of that experiment.) This number is called the **density** of the water. So we may have density of iron, kerosene, or any other kind of matter. State a definition for density according to your idea here obtained.

b. There are 28.35 g. in 1 oz. Compute from the result obtained in Exp. 6 the weight in *pounds* of 1 cu. ft. of water. Keep two decimal places. Is your work accurate and your result correct? State the correct result, the amount of your error, and the percentage of error.

Second Part — Density of Wood.

Apparatus. — A rectangular block of wood with a volume of about 400 cc.; a balance with weights; a meter stick.

Directions. — *c.* Find the average length of the block by measuring each of the four edges which are parallel with the grain of the wood. Find the average width by measuring each of four other edges which are parallel to each other. Find the thickness similarly. Compute the volume of the block.

d. Find its weight. What is the weight (mass) in grams of 1 cc. of this wood? This number is called the density of the wood.

e. What is the weight of a volume of water equal to the volume of the wood? How many times is the weight of the water contained in the weight of the wood? The result is called the **specific gravity** of the wood. From what you have here learned, define specific gravity. Make the definition short.

f. Do you find any similarity between the density and the specific gravity of wood?

Experiment 40. To Determine the Specific Gravity of an Irregular Solid which will Sink in Water and which is not Soluble in Water.

Apparatus. — A suitable balance; weights; several solids, the specific gravity of each of which is to be determined; thread; a jar of water.

Directions. — *a.* Weigh the solid in air.

b. Using as little thread as possible, tie the thread to the solid and suspend it from the hook of the balance, as in Fig. 36. Place the jar of water

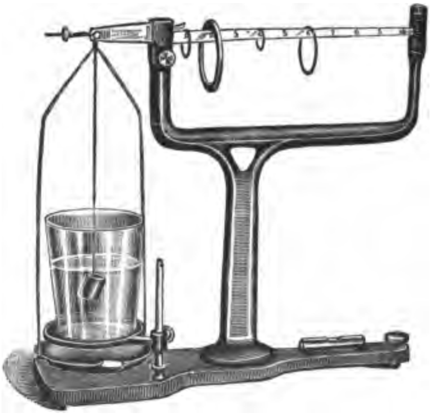

FIG. 36. — Chaslyn Balance.

so that its weight shall not be supported by the balance beam, but so that the solid shall be immersed in the water. See that no air bubbles are clinging to the solid. Weigh the solid once more in this position. Does it weigh the same as before (see Exp. 37, *e*)?

c. By Archimedes's Principle (see Exp. 37) determine the volume of the solid.

d. What is the weight of the same volume of water?

e. What, then, is the specific gravity of the solid (see Exp. 39, *e*)?

f. In the same manner determine the specific gravity of the several substances and tabulate results as follows, where "Difference" means difference between your result and that given on p. 296 of the Appendix. This is not necessarily an error, as the specific gravity of different specimens of the same substance may vary within wide limits.

	Name of Substance	Weight in Air	Weight in Water	Loss (Weight of Equal Volume of Water)	Volume in cc.	Specific Gravity as obtained	Specific Gravity from Table	Difference	% of Difference
1		. . . g.	. . . g.	. . . . g.					
2									
3									
etc.									

g. In Exp. 37 the volume and weight of a certain brass cylinder were learned. Without further measurements compute its specific gravity.

Note 1. — Archimedes's Principle may be used to determine the diameter of a wire as follows: Determine the length of the wire and its weight in air and water. From this calculate the volume of the water displaced and therefore the volume of the wire. The volume is equal to the area of cross-section multiplied by the length. Therefore the area of cross-section is equal to the volume divided by the length. From the area may be learned the diameter by computation or by consultation of tables. Test your result by actual measurement with micrometer caliper.

Note 2. — For accurate work in this experiment and in all work in specific gravity, corrections must be applied, as in Exp. 6, Note 3.

Experiment 41. To Determine the Specific Gravity of a Solid Denser than Water by Means of the Jolly Balance.

Explanation. — It was found in Exps. 14 and 15 that elongation is proportional to stress, so that, in the case of a spiral spring, the elongations are proportional to the forces producing them. The elongation of the spiral spring may, therefore, be used as a measure of the force causing the elongation. If the elongation per unit force (weight) is known, the weight of a given body can be calculated by measuring the elongation it produces.

These remarks show that the Jolly Balance (Fig. 17), is really a balance; that is, an instrument for the comparison of masses.

The method of determining specific gravity by means of the Jolly Balance is very convenient and accurate when application of Archimedes's Principle is made.

Apparatus. — A Jolly Balance with two pans; a glass tumbler or a beaker; small solids whose specific gravity is to be determined.

Directions.—*a.* Level the balance as in Exp. 15, *a.* Then adjust the spring so that the index is somewhat below the middle division of the scale. Place the tumbler, nearly filled with water, on the support, and raise the support until the lower pan and most of its supporting wires are beneath the surface of the water. Note accurately the point on the supporting wires which is just at the water surface. Perhaps this can best be determined by looking underneath the water surface, as in Exp. 38. *Be careful not to wet the upper pan.* If it should happen to get wet, dry it thoroughly. The lower pan must not touch the tumbler.

b. Read the position of the index, estimating to tenths of a millimeter, keeping the eye in such a position that the index just covers its image in the mirror scale.

c. Place the solid whose specific gravity is to be determined in the upper pan, holding the pan so that it will not become wet, and lower the tumbler until, when the spring hangs freely, the lower pan is submerged to exactly the same extent as in *b.* Read the position of the index.

d. Place the solid in the lower pan. See that it is free from air bubbles. Raise the support until the lower pan is submerged to the same extent as in *a* and *c*, and read as before.

e. Record results as below, where "Difference" means the difference between your result and that given in the Appendix, p. 296. This is not to be considered an error necessarily (see Exp. 40, *f*).

	Substance	Reading with Pans Empty, as in *b*	Reading with Solid in Upper Pan, as in *c*	Reading with Solid in Lower Pan, as in *d*	Elongation Due to Weight in Air W	Elongation Due to Weight in Water W'	Specific Gravity $\frac{W}{W-W'}$	Difference	% of Difference
1									
2									
3									
etc.									

Experiment 42. To Determine the Specific Gravity of an Irregular Solid that will Float in Water.

Apparatus. — A balance; weights; a piece of paraffine, or cork soaked in hot paraffine to make it waterproof, whose specific gravity is to be determined; fine thread; a jar of water; a piece of lead heavy enough to cause the paraffine to sink in the water.

First Method.

Directions. — *a.* Weigh the paraffine in the air.

b. Attach the sinker to the paraffine and weigh both entirely submerged in the water.

c. Weigh the sinker alone in water.

d. From these three weights only, calculate the specific gravity of the paraffine as follows:

1) Find the weight of the paraffine in water by subtracting the weight of the sinker in water from that of both in water. Do you find this to be a negative quantity? Must it necessarily be so? Does this mean that

the paraffine weighs less than nothing in water (see Exp. 37, *e*); that in order that its apparent weight shall be just zero, something must be added to its weight?

2) Subtract this result from that found in *a* above, and thus find the loss of weight of the paraffine in water. Will this be the weight of an equal volume of water, as is usually the case? Conclude your work as in other cases.

Second Method.

e. Weigh the paraffine and the sinker separately in air.

f. Weigh the two together submerged in water.

g. Weigh the sinker alone in water.

h. How much do the two together weigh in air? How much is the loss of the two in water? How much is the loss of the sinker in water? The difference between the last two, then, must be the loss of the paraffine in water. Will this also be the weight of a volume of water equal to the volume of the paraffine? Finish as usual.

Experiment 43. To Determine the Specific Gravity of Solids Less Dense than Water by Means of the Jolly Balance.

Apparatus. — A Jolly Balance (Fig. 17); a tumbler or a beaker of water; a sinker (lead is best); a solid whose specific gravity is to be determined, such as beeswax, cork or paraffine; fine thread.

Directions. — *a.* Adjust and read the balance as directed in Exp. 41, *a* and *b*.

b. Place the solid in the upper pan and note the elongation of the spring.

c. Remove the solid and note the elongation when the sinker is in the lower pan, immersed in the water.

d. Fasten the sinker and solid together, using as little thread as possible; and note the elongation when both are in the lower pan immersed in water.

e. Record results in the following table, where "Difference" has the same meaning as in Exps. 40 and 41.

	Substance	Reading of Balance, Pans Empty, as in *a*	Reading with Solid, in Upper Pan, as in *b*	Reading with Sinker, in Lower Pan, as in *c*	Reading with Sinker and Solid, in Lower Pan, as in *d*	Elongation Due to Weight in Air, as in *b* W	Elongation Due to Weight of Sinker in Water, as in *c* W''	Elongation Due to Weight of Sinker and Solid in Water, as in *d* W'	Specific Gravity $\frac{W}{W-(W'-W'')}$	Difference	% of Difference
1											
2											
3											
4											
etc.											

NOTE. — Attention is again called to the fact that the instructions given for the use of the Jolly Balance in Exps. 15, 41, 43, and 47 apply to the ordinary form, rather than to the vernier form shown in Fig. 17 (see Exp. 15, Note 3).

Experiment 44. To Determine the Specific Gravity of a Liquid by Means of a Specific Gravity Bottle.

Apparatus. — A balance; weights; a specific gravity bottle as in Fig. 37; alcohol or some other liquid to be tested.

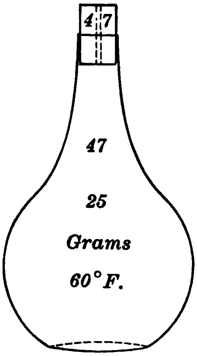

FIG. 37.—Specific Gravity Bottle.

NOTE. — The specific gravity bottle is a small flask, having a volume of 10, 25, 50 or 100 cc. as may be, and closed by an accurately fitting glass stopper with a capillary opening through it. The capacity is usually stated in grams (or "grammes") instead of cc., meaning that the bottle will hold that mass of water. The volume is usually marked on the bottle, and, moreover, the temperature at which this volume is correct. See that the numbers on the stopper and bottle agree, as these two were originally ground to fit, and others will not fit. Much time may be saved by providing a counterpoise for the bottle and stopper. In that case see that the number stamped on it agrees with that on the bottle and stopper.

Directions. — *a*. Thoroughly clean and dry the bottle as in Exp. 12, Note. Find the weight of the bottle and stopper together. This will be unnecessary if a counterpoise is provided. In that case place the counterpoise in the other pan and proceed with *b*.

b. Fill the bottle with alcohol. Put the stopper in place carefully but firmly, giving the surplus liquid time to escape through the hole in the stopper. **Be careful to warm the bottle and contents as little as possible by handling.** Dry the outside of the bottle, and be sure that it contains no bubbles of air. Be very careful that none of the liquid is brought in contact with the scale-pan.

c. Weigh bottle and contents. Compute the weight of the contained alcohol. You know by observation what this volume of water would weigh.

d. Compute the specific gravity of the alcohol. Return the alcohol and rinse the bottle and stopper thoroughly.

NOTE 1. — For more accurate results, or for testing the capacity of the bottle, see Stewart & Gee, Vol. I, p. 127.

NOTE 2. — If a second liquid is to be tested, rinse out the bottle with a little of this liquid and proceed as before.

Experiment 45. To Determine the Specific Gravity of a Solid in Small Quantity by Means of a Specific Gravity Bottle.

Apparatus. — A specific gravity bottle; the solid to be tested, in pieces small enough to enter the bottle; a balance; weights; water.

Directions. — *a.* Weigh the bottle (see Exp. 44, *a*).

b. When filled with water and properly arranged, what weight of water will the bottle contain? Weigh the solid.

c. Put the solid in the bottle; fill it with water, observing all precautions, as in Exp. 44. Weigh the bottle and contents.

d. Calculate the

Weight of contents.
Weight of the solid in the bottle (already known).
Weight of the water in the bottle.

e. Does the solid displace, or keep out of the bottle, its own volume of water? What is the weight of this volume of water?

f. Calculate the specific gravity of the solid.

NOTE.—It may be noticed that in the determination of specific gravity it is not necessary to know what volume of the two substances is used so long as these two volumes are *equal.* However, if we know the weight of the water in grams, we do know at once its volume.

Experiment 46. To Determine the Specific Gravity of a Liquid by Weighing a Solid in it and in Water. (By Sp. Gr. Bulb.)

First Part.

Apparatus.—A balance; weights; a beaker of alcohol or other liquid to be tested; a glass stopper of a bottle with thread for suspension, or something similar.

Directions.—*a.* Weigh the stopper in air.

b. Weigh the stopper immersed in water.

c. Dry the stopper and weigh it immersed in alcohol.

d. Is the same volume of liquid displaced in each case? Is the loss of weight of the stopper the same in each case? A volume of water equal to the volume of the stopper has what weight? The same volume of alcohol has what weight?

e. Calculate the specific gravity of the alcohol.

NOTE.—Always wash and dry the stopper carefully before transferring it from one liquid to another. The same corrections for temperature apply here as in preceding work.

Second Part.

Additional Apparatus.—Other liquids to be tested, such as benzine, kerosene, glycerine, sulphuric acid, solutions of salt, ammonium chloride, copper sulphate, etc.

Directions.—*f*. As in *a*, *b*, *c*, above, then weigh the stopper in kerosene.

g. The loss of weight of the stopper in each of these liquids determines the weight of a volume of the liquid equal to that of the stopper in each case. The weight of the alcohol divided by that of the kerosene will be the specific gravity of the alcohol *referred to kerosene as a standard.*

In this way determine the specific gravity (**relative density**) of the

Alcohol referred to water as a standard (already known).
Alcohol referred to kerosene as a standard.
Water referred to alcohol " "
Water referred to kerosene " "
Kerosene referred to water " "
Kerosene referred to alcohol " "

So any substance might be chosen for the standard. For many reasons, however, it seems best to select water for the standard, and this is done.

NOTE. — If sulphuric acid is used, a platinum wire must be used for suspension.

Experiment 47. To Determine the Specific Gravity of a Liquid by Means of the Jolly Balance.

Apparatus. — A Jolly Balance (Fig. 17); a glass stopper or something similar; a tumbler of water and another of the liquid whose specific gravity is to be determined; fine thread.

Directions. — *a.* Remove the two pans and substitute the glass stopper supported by a thread. Read the position of the index.

b. Place the tumbler of water on the support and raise it until the glass stopper is submerged. Read the position of the index.

c. Remove the stopper from the water and dry it thoroughly. Remove the tumbler of water and substitute the tumbler of liquid whose specific gravity is to be determined. Immerse the stopper as before and note the reading.

d. Record results in the following table:

Liquid	Reading with Stopper in Air	Reading with Stopper in Water, as in *b*	Reading with Stopper in the Liquid, as in *c*	Elongation Due to Weight in Water L	Elongation Due to Weight in the Liquid L'	Specific Gravity $\frac{L}{L'}$	Difference	% of Difference

Experiment 48. To Determine the Specific Gravity of a Liquid which does not Mix with Water, by Means of a U-Tube.

Apparatus. — A U-tube as in Fig. 38 (see Note 2 below); water; liquid to be tested, such as kerosene, mercury, or turpentine; a meter stick.

NOTE 1. — In this experiment the effect of capillarity will be ignored.

Directions. — *a.* Pour the heavier of the two liquids, in this case the water, into the tube first. Fill the tube about one-third full of the liquid. If the tube is quite small, it may be well to use a funnel connected to the U-tube by a short piece of rubber tubing for this purpose. Now slowly pour the second liquid, kerosene, on top of the first, being careful not to drive the first entirely around the bend at the bottom. The lighter liquid *ON* (Fig. 38) should nearly fill the straight part of one arm, the heavier one occupying the portion *PMN*. Add more of the first liquid if necessary. *M* and *N* being on the same level, is it evident that the portion of liquid in one arm below this level is exactly balanced by the portion in the other arm below the same level? What, then, is true of *ON* and *PM*? What follows concerning the relative weights, or relative densities, or specific gravities of the two liquids?

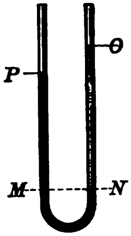

FIG. 38.

b. Measure carefully the vertical distances *ON* and *PM*. This may best be done by resting the tube on the table and making all measurements from the table-top. Be careful to measure vertically in all cases, likewise always to measure to the center of the meniscus.

c. From these measurements calculate the specific gravity of kerosene.

d. What difference would it have made in the results if the diameter of one arm of the tube were four times that of the other?

NOTE 2. — It is well to have the U-tube fastened permanently to an upright support. If the support allows, a second U-tube may be attached to the other side and thus allow different liquids to be experimented with. If so arranged, the liquids should be left in the tubes during the work on Specific Gravity.

Note 3. — In this and other experiments where equal *weights* are obtained, instead of equal *volumes*, the specific gravity may readily be determined by first calculating what the weights of *equal volumes* would be.

Experiment 49. To Determine the Specific Gravity of any Liquid by Means of a Y-Tube (Hare's Method).

Apparatus. — The Y-tube apparatus of Exp. 32 (see Fig. 39); two vessels, one containing water and the other a saturated solution of salt or other liquid to be tested.

Note 1. — A "saturated" solution of salt means as much salt as possible dissolved in water. To be sure of this, there should always be some undissolved salt at the bottom of the liquid. This undissolved salt is not to be used.

Directions. — *a.* Place the end of one tube in the vessel of water, the end of the other in the salt solution. Remove the pinchcock. Note the height to which the liquid rises in each tube because of capillarity. *Measure vertically.*

b. Cause the liquids to rise in the tubes by "sucking" air from them till one liquid rises nearly to the top of its tube. Be careful that it does not flow over the top into the other tube. If it does, throw away the mixture and begin anew. Are the liquids *pulled* or *pushed* up into the tubes? How? With the pinchcock close the rubber tube air-tight. This will be the case if the liquids remain stationary at their respective levels. When satisfactory, measure *vertically* the distances *MN* and *OP* (Fig. 39), making the necessary correction for capillarity.

NOTE 2. — This experiment is really a variation of Exp. 48. In this experiment (49) the air *MO*, confined in the top of the tubes, is exerting the same pressure on *unit area* on each of the liquid surfaces at *M* and *O*. The upward atmospheric pressure at *N* within the tube, per *unit area,* is also equal to that at *P* within the tube, per *unit area.* Is it true that the pressure of the column of liquid, *MN*, at *N* per *unit area* produced by its weight is equal to the pressure of the column *OP* at *P* per *unit area* produced by *its* weight? Would it, then, follow that if these two columns met at the bottom they would just balance each other? Would their weights then be equal?

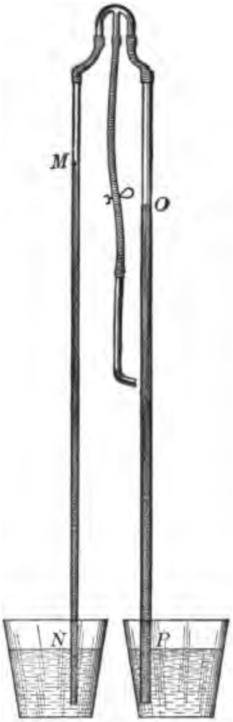

FIG. 39.

c. From the measurements in *b* calculate the specific gravity of the salt solution.

d. Will it make any difference whether the tubes are of the same size? Repeat *a*, *b*, and *c*, using water in the tube used previously with salt solution and *vice versa* (see Exp. 32, *b*). Look out for capillarity.

e. Must the liquids in the two vessels necessarily be on the same level? Repeat *d* with them at different levels. Return the salt solution and rinse out *thoroughly* all apparatus which has been touched by it.

f. Find the average of the results obtained in *c*, *d*, and *e*, and call this the specific gravity of the salt solution.

Note 3. — The relative densities of any two liquids (see Exp. 46, *g*) might be determined in this way.

Experiment 50. To Determine the Specific Gravity of a Liquid by Means of a Hydrometer.

Apparatus. — The loaded wooden bar of Exp. 38; a tall jar of water and another of the salt solution or other liquid whose specific gravity is to be determined. Each jar must be tall enough to contain the bar.

Directions. — *a.* Float the bar in water and note the portion submerged; that is, the amount of water displaced. For this purpose look *underneath* the surface, as in Fig. 35, to escape the inaccuracy caused by capillarity where the liquid touches the bar. What is the volume of this displaced water? What is its weight? What, then, is the weight of the bar (see Exp. 38)?

b. Dry the bar and float it in the salt solution. Note the portion submerged; that is, the volume of the salt solution displaced. What is the weight of salt solution displaced?

c. From these measurements determine the specific gravity of the salt solution.

Note 1. — The bar used in this experiment is ordinarily called a **hydrometer,** though more properly a **densimeter.** In practice it is usually made of glass, and somewhat different in shape.

Note 2. — The specific gravity of the hydrometer itself, or of any other floating body, may be readily determined by this method of flotation *if the liquid be water.* For, since a floating body displaces its own weight of the liquid, it follows that if the body floats when it is exactly even with the surface of the liquid, its volume is precisely the same as that of the liquid displaced; and since the weights are equal, its specific gravity is 1. While if it sinks till only half its volume is submerged, it weighs only one-half as much as a volume of the liquid equal to its own volume, and its specific gravity, therefore, is 0.5.

NOTE 3. — Has the human body a specific gravity much greater or much less than 1? Why does filling the lungs with air help one to float in water? Try this when in the bath-tub and note any change in the level of the water.

Experiment 51. — To Determine the Specific Gravity of an Irregular Solid that will Sink in Water, but which is Soluble in Water.

Apparatus. — A balance; weights; thread; crystal of copper sulphate to be tested; a vessel containing a saturated solution of copper sulphate or some other liquid in which the crystal is insoluble.

NOTE 1. — A **saturated solution** of copper sulphate contains *all* the copper sulphate it will dissolve; therefore, this crystal and this solution are satisfactory for our use. (Copper sulphate is also insoluble in turpentine; rock salt in naphtha; saltpetre and rock candy in alcohol; alum in turpentine, etc.)

Directions. — *a.* Determine the specific gravity of the liquid in any way other than by the specific gravity bottle. This method might be used, but there is danger of the stopper being sealed into the bottle by a little carelessness in cleansing.

b. Determine the density of the crystal of copper sulphate as compared with that of the solution of copper sulphate. This is to be done exactly as in Exp. 40, except that the solution of copper sulphate is to be used in place of water.

c. What is the weight of the crystal of copper sulphate? What is the weight of the same volume of the solution of copper sulphate? What is the weight of the same volume of water? This is determined from the specific gravity of the solution of copper sulphate, which is already known. What, then, is the specific gravity of the crystal?

NOTE 2. — It has been learned that a solid weighs less in alcohol than in air; less in water than in alcohol; less in a solution of copper sulphate than in water, etc. This is because each of these liquids exerts its own buoyant effect on the solid. Is it possible that when a body is weighed in air the air exerts a precisely similar influence on it? Suppose a body to be weighed in a vacuum. Will it weigh more or less than when weighed in air? Why? How much? Is the weight of a body in air, then, its *true* weight? How could its true weight be determined *practically?*

HEAT.

General Note. — In the work in *Heat* much time will be saved if a vessel is provided for holding water that may be kept at the temperature of the room, from which pupils may take water for experiments when it is needed at that temperature. Also a reservoir should be provided for hot water, so that time will not be taken by the pupils for heating it. If access can be had to a steam pipe with a faucet, the exhaust steam will heat water very quickly. In this work in *Heat* be very careful that the heat of the body, the breath, the sun or any other outside source does not affect your result. In reading a thermometer estimate tenths of a degree. Never bring a thermometer near a flame.

Experiment 52. A Source of Heat.

Apparatus. — A 150 cc. flask or bottle with a stopper; mercury; a thermometer; a thin piece of sheet lead; a gimlet; a piece of soft wood.

Directions. — *a.* Place a few cubic centimeters of mercury in the flask. With the thermometer accurately note its temperature, which should be about the same as that of the room. Estimate tenths of a degree. Close the flask with the stopper; wrap it in *many* thicknesses of paper, to protect from the heat of the hand, and shake *vigorously* for two or three minutes.

b. Note the change in temperature of the mercury. Shake again for a few minutes and note the temperature as before.

c. Rub the piece of sheet lead on the piece of wood. Note by the hand any change in temperature.

d. Bore a hole in the piece of wood with the gimlet. Note by the hand any change in the temperature of the point of the gimlet.

e. What is the cause of the increase of temperature noticed in this experiment? What transformation of energy is shown?

NOTE. — Water may be used in place of the mercury if desired, though not as satisfactorily.

Experiment 53. Effect of Heat on Matter.

Apparatus. — A beaker of water; an air thermometer (this is a glass bulb 4 or 5 cm. in diameter, with a straight tube about 20 cm. long and 1 or 2 mm. internal diameter; see Fig. 40); a 150 cc. flask with a one-hole stopper containing a glass tube about 20 cm. long and 1 or 2 mm. internal diameter. (This flask and tube so arranged might answer for the air thermometer.)

Directions. — *a. Gases.* Dip the open end of the air thermometer in the beaker of water. Warm the bulb by clasping with the hand. Note the effect. Still keeping the end of the tube in the water, allow the bulb to cool. Apply cold water to the bulb. Explain the effect noticed.

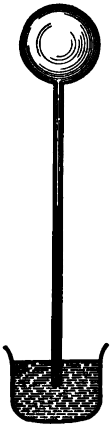

FIG. 40.

NOTE. — When through with the air thermometer leave it with no water inside. The bulb is of very thin glass. Be careful not to squeeze it, as it might break and cut the hand.

b. Liquids and Solids. Fill the flask with cold water from the faucet. Insert the stopper and tube so that no air bubbles are left in the flask. The water should stand in the tube at least 1 or 2 cm. above the stopper. Now heat the flask by dipping it into hot water. If you watch closely at the time of applying the heat, you will notice that there is a slight fall of the water surface in the tube at that instant, after which the liquid expands and rises in the tube. Explain the cause of the fall at first.

c. What is here found to be the effect of heating a solid? a liquid? a gas?

Experiment 54. Heating of Solids.

Apparatus. — A Bunsen burner; a board with four grooves, in which are fastened wires of copper, brass, iron, and German silver, about No. 16, twisted together at *A* (see Fig. 41). After the wires are mounted these grooves are filled with paraffine (see Note, p. 202).

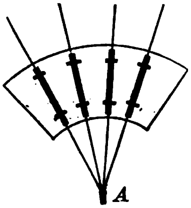

FIG. 41.

Directions. — *a.* Heat the wires at *A* with the Bunsen flame for a short time. In a few minutes the paraffine around the wires will begin to melt. The melting point of paraffine being constant, the places on the wires farthest from the flame, where the paraffine melts, have the same temperature; measure these distances. Or the wires may be mounted without the paraffine. In that case, move the tip of a finger carefully along each wire toward the flame, until a point is reached which is uncomfortably warm. Measure the distance from this point to the flame. Name the metals used in order of their ability to conduct heat. See Appendix, p. 299.

b. Is any movement of the metals noticed because of the heat? The process by which heat is here transmitted is called **conduction.**

Experiment 55. Heating of Liquids.

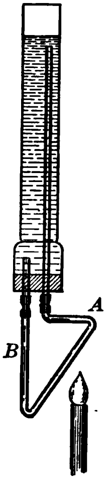

Fig. 42.

Apparatus. — Test-tube; water; Bunsen burner; a chip of ice as large as can be placed in the test-tube; a piece of bent wire or a piece of lead for holding the ice at the bottom of the test-tube; a large glass beaker; fine sawdust; retort stand; Argand lamp chimney fitted with a two-hole rubber stopper and glass tubing, as shown in Fig. 42, nearly filled with water containing a little fine sawdust; stopper to fit the top of the chimney.

Directions. — *a.* Drop the ice into the tube, and on top of it place the wire or lead, in order to keep the ice at the bottom. Fill the test-tube nearly full of cold water. See that the outside of the tube is thoroughly dry. With the bottom of the tube held in the hand incline it slightly and apply the tip of a flame to it near the top. Keep the tube moving slowly while in the flame. **Take care that the flame does not touch any part of the glass not covered by the water.** Hold the tube in this position until the water at the top boils. Do not allow it to boil over. How is the temperature of the lower end of the tube affected? What does this show as to the ability of water to conduct heat?

b. Nearly fill the beaker with water containing a little sawdust. Before heating the beaker see that the outside is perfectly dry. Then, having placed it on the retort stand, *gently* heat the beaker at the bottom, close to one side. Notice the liquid currents as indicated by the motion of the sawdust.

c. Using the apparatus of Fig. 42, apply the flame as shown. In what direction do the currents seem to move from the flame? Remove the flame. With the chimney filled with water, insert a stopper, invert the apparatus and cool the tube at *A* by touching it with a piece of ice or a ball of snow. In what direction does the current flow from *A*?

d. Why does the heated water rise? Why does the cooled water sink? The process by which heat is here transmitted is called **convection.**

Experiment 56. Heating of Gases.

Apparatus. — Battery jar or large bell jar; Argand lamp chimney; strip of tin which will just slip into the chimney and reach from the neck to the top, or beyond; candle about 3 cm. long; touch paper, which is made by dipping strips of unsized paper into a strong solution of potassium nitrate (saltpetre), the paper then being dried before using.

Directions. — *a.* Set fire to a strip of the touch paper, and by means of the movements of the smoke study the directions of the air currents in the room. Study, too, the currents near the top and bottom of an open window or door. The smoke, being made up of solid, visible, and very light particles, serves to indicate the air currents.

b. Hold a small piece of the lighted paper under an inverted battery jar. Make a sketch illustrating the air currents caused by the burning paper.

c. Light the candle; set it on a paper on the table, and over it the lamp chimney. Result? Divide the chimney into two parts by placing the strip of tin in it. Now place the chimney over the lighted candle so that the candle will be a little at one side of the tin strip. Result? Hold the burning paper above the chimney-top, first over one part, then over the other. Sketch the result.

d. Compare the method of transmitting heat here with that of Exps. 54 and 55. Name this method.

Experiment 57. To Determine the Error in the Location of the Zero Point (Centigrade) of a Mercurial Thermometer.

Apparatus. — Thermometer; vessel of about 200 cc. capacity; *clean* ice or snow; retort stand or burette stand with clamp.

NOTE 1. — *Never touch the bulb of a thermometer*, as heat is thereby imparted to it, and it may be necessary to wait a long time for it to return to the proper temperature. In handling the instrument, hold it by the top only. Every thermometer should be numbered. Any thermometer will in time become inaccurate for various reasons. Every thermometer should have its corrections for various temperatures noted for use in accurate work. In the notebook give a minute description of the thermometer used, accompanied with a sketch. If the ice is brought in from out of doors in cold weather, it may be colder than 0° C. In that case, time must be allowed for it to reach the melting point before using it in such work.

Directions. — *a.* Support the thermometer in a clamp of the retort stand, so that the zero mark will be a little above the level of the rim of the vessel.

b. Pack snow or ice shavings around the bulb and stem of the thermometer so that the zero line is just plainly visible.

c. Read the position of the mercury at intervals of about a minute (estimating tenths of a degree), until three consecutive readings are the same. This is the correct **freezing point** (melting point) as indicated by this particular thermometer.

d. Enter results thus :

Thermometer number . . . .
Graduation of stem extends from............° to ....°C.
Freezing point observed . . . . . ± ....°
Error in the location of the zero point ± ....°

NOTE 2. — Temperatures below zero should be prefixed by the minus sign, –; thus, – 4°, – 10°. The plus sign, +, for temperatures above zero is usually omitted, as in algebra. In *d* use either the positive or negative sign, according to the results observed.

NOTE 3. — To determine whether a thermometer tube has a uniform bore (its accuracy depends in part upon this fact), jar a portion of the mercury column loose and cause it to take various positions along the tube. Variations in its length will denote corresponding irregularities in the bore (see Exp. 58, Note 2).

Experiment 58. To Determine the Error in the Location of the 100°-Point (Centigrade) of a Mercurial Thermometer.

Apparatus. — Thermometer (the *same* one used in the previous experiment); a long-necked flask, or, *better*, the Harvard "Apparatus *A*" (Fig. 43), which will hereafter be called a "boiler" (see Appendix, p. 274); barometer; retort stand with clamp; Bunsen burner.

Directions. — *a.* If a flask be used, fill it about one-third full of water and suspend the thermometer by the clamp of the retort stand so that its bulb shall be about 2 cm. above the water. If a boiler be employed, fill it about one-third full of water and pass the thermometer through a perforated stopper, fitting the hole *F* at the top, till the 100° mark is just above the stopper; the upper side-tube, *A*, should be open; the lower one, *B*, closed.

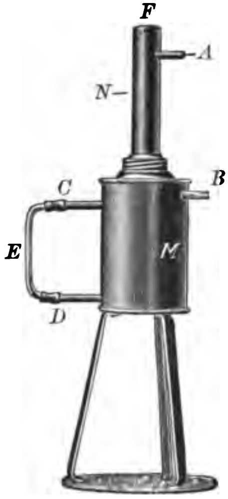

FIG. 43. — Boiler.

b. Boil the water vigorously. When the mercury remains stationary for a couple of minutes, record its position (estimating tenths of a degree). This is the **boiling point** as indicated by *this* thermometer.

c. The boiling point of water is 100° C. when the atmospheric pressure is 760 mm. or 29.922 in. (the standard). This, however, is seldom the case, and correction must therefore be made as follows: If the atmospheric pressure be doubled (1520 mm.), the boiling point of water would be raised to 120.6° C. If the atmospheric pressure be halved (380 mm.), the boiling point would be lowered to 81.5° C.; therefore to find the true boiling point at the present time read the barometer, making corrections as in Exp. 32, *d*, (1) and (2), and compute the true boiling point, t, of the water by the formula $t = 100° - 0.0375\,(760 - b)$ where b is the corrected barometric reading expressed in millimeters. Or the correction for pressure, that is, the true boiling point under present conditions, may be found by subtracting 1° from 100° C. for every 26.8 mm. that the barometer is *below* 760 mm., or adding 1° for every 26.8 mm. *above* 760 mm. It is a fact that a change in pressure also produces a change in the *freezing point* of water; but as it is only about one-thousandth as much as in the boiling point, this correction was neglected in Exp. 57.

d. The error of the 100° point of *this* thermometer is the difference between the observed and true boiling points.

Enter results thus:

Thermometer number . . . .
Graduation of stem extends from ....° to ....° C.
Height of barometer .... in.,
Corrected height, ... in. = ... mm.
Observed boiling point . . . .° C.
True boiling point (computed) . . . .° C.
Error in the observed boiling point (see Note 1 below) . . . . C.
Error in the 100° point (practically the same as the error of the observed boiling point. See Note 1 below) . ...° C.

Note 1. — It should be observed that the computed boiling point as obtained in *c* is *correct.* If the observed boiling point differs, it is wrong, and the fault lies in the fact of the thermometer not being correctly graduated. It will be sufficiently accurate to consider the error of the 100° point of the thermometer the same as the error of the *observed* boiling point. A lens or reading glass facilitates the estimation of tenths of degrees. Care must be taken to avoid parallax.

Note 2. — *For accurate work* a thermometer should have its readings at various temperatures compared with those of a standard thermometer. A correction "curve" should then be constructed for the thermometer, from which approximate corrections may be obtained for *any* reading. Thereafter both the *observed* and *corrected* readings should always be stated.

It is advisable in the above study of the fixed points of a thermometer to first determine the zero point, then the boiling point, and finally the zero point a second time. There is a constant rise in the freezing point of a thermometer with age, due to a slow and steady contraction of the glass bulb. A thermometer graduated the day it is filled will read a degree and a half higher a week later. Such a change in the freezing point changes the whole series of indications equally. After a thermometer has been heated to such a temperature as the boiling point there is a depression of the freezing point of about 0.4 of a degree, which is fully recovered in about six weeks. Long exposure to a low temperature, as – 30°, will raise the freezing point about 0.1 of a degree. (Weather Bureau, "Instructions to Voluntary Observers," 1892, pp. 13 and 14.) Jena glass is comparatively free from these changes.

Experiment 59. To Determine the Melting Point of Paraffine.

Apparatus. — Thermometer; retort stand with ring; wire gauze, asbestos board, or sand bath; Bunsen burner; small beaker; paraffine; glass tubing about 5 or 10 mm. diameter and 10 cm. long; two small rubber bands.

Preliminary. — Soften in the flame the middle part of the glass tubing and draw it out to a diameter of about a millimeter. Let it cool, and break into two similar pieces at the middle. Dip the capillary portion of the tube into melted paraffine, so that when it cools there will be a thread of paraffine in the tube. Fuse the glass together at the drawn-out end. Fasten this capillary tube, filled with paraffine, to the thermometer by means of two rubber bands, so that the bulb of the thermometer and the paraffine are side by side.

Directions. — *a.* Place a beaker nearly full of water on the wire gauze on the retort stand and heat it *slowly* with the Bunsen flame, stirring gently all the while with the thermometer and attached capillary tube.

b. Watch the thread of paraffine closely, and when it begins to become transparent, read the thermometer and cease heating the water. This is the **melting point** of the paraffine. Record it.

c. Let the water cool, stirring gently, and record the temperature when the paraffine begins to become opaque again. This is the **congealing point.**

d. Obtain at least three readings for each of these points. Tabulate and find the mean of all results. This mean will be the true melting point (congealing point) of the particular paraffine used.

Experiment 60. The Boiling Point under Various Conditions.

Apparatus. — Boiler (see Exp. 58); thermometer; retort stand with test-tube clamp; two short pieces of rubber tubing; two pinchcocks; salt; a 6-in. side-neck test-tube, with a one-hole stopper and a glass tube, *A*, as in Fig. 44, with a short piece of rubber tubing, *C*, on its outer end; a glass tube, *B*, as in the figure; an air pump; tumbler of water; Bunsen burner.

Directions. — *a.* Fill the boiler with water to a depth of about 10 cm. Push the thermometer through the stopper, *F*, of the boiler until the 100° mark is just above the stopper. Leave both side tubes, *A* and *B*, open. Boil the water for two or three minutes or until the mercury of the thermometer is stationary. Record the temperature.

b. Close both side tubes with the pieces of rubber tubing and pinchcocks and continue the heating until a change is noted in the temperature. Then, *at once*, remove the flame. What effect on the enclosed vapor besides change in temperature.

c. Take off the top, *N*, of the boiler and withdraw the thermometer from the stopper. Again apply the flame and hold the thermometer so that the bulb dips below the surface of the water. *Be careful that the bulb does not touch the side nor the bottom of the apparatus.* While the water is boiling, note the temperature. Compare with results obtained in *a*.

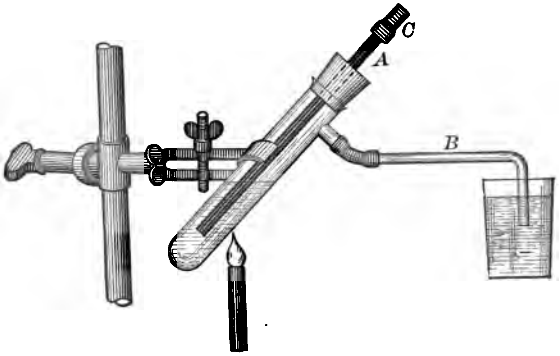

FIG. 44.

d. Add to the water about a tablespoonful of salt. Boil again as in *c*. What effect on the temperature and why?

e. Fill the side-neck test-tube about one-third full of water. Arrange the apparatus as in Fig. 44, allowing the tube *B* to dip one or two centimeters below the surface of the cold water in the tumbler. See that tube *A* extends nearly to the bottom of the test-tube. Boil the water by applying the *tip* of a flame to that part of the test-tube which contains the water.

Caution. — Be careful not to allow the flame to touch the glass above the water line.

NOTE. — Two kinds of bubbles may be looked for in the test-tube and tumbler — air bubbles which will rise to the surface of the water in the test-tube and tumbler before disappearing, and bubbles of water vapor (steam) which at first disappear before reaching the surface; but as the upper layers of water become heated they also rise to the surface and disappear.

f. Notice carefully any of the first bubbles that appear and describe any peculiarity in their behavior. Are they air or water vapor?

g. As the boiling continues, note carefully any change in the character and behavior of the bubbles. Describe the change, if any is noticed.

h. After the boiling has continued for a minute or two, remove the flame and notice what happens, particularly in the tubes *A* and *B*. While this action still continues, close tube *C* for a moment with the finger and note the result. Give the reason for the result noticed.

i. With the test-tube about one-third full once more, and with tube *C closed by a pinchcock*, remove the tumbler of water and again boil the water in the tube. Take away the flame, connect the side tube with the air pump, and *slowly* exhaust the air (?) in the tube. Result? Why? Or, after boiling, close the outlet and allow a *small* stream of *cold* water to trickle on that portion of the test-tube not covered with water inside. Result? Why?

j. What are your conclusions as to the effect on the boiling point of liquids, of increased pressure, diminished pressure, and the presence of foreign substances, salt, for instance.

Experiment 61. Evaporation.

Apparatus. — Bunsen burner; retort stand; wire gauze; beaker of water; piece of window glass; alcohol; ether; air thermometer (see Fig. 40).

Directions. — *a.* Place the beaker of water on the wire gauze on the retort stand and cover it with the window glass. Light the Bunsen burner and *gently* heat the beaker, being careful *not to let the water boil.* After a moment take off the glass and note what is on its under surface. Where did this come from?

b. Place on the hand a drop of water at about the temperature of the room. Allow it to remain a moment. Does it evaporate rapidly? Repeat with alcohol, and then with ether. All three have about the *same temperature.* Which one *feels* the coldest? Which one evaporates the fastest? What connection is there between these last two phenomena?

c. Repeat *b*, using the air thermometer instead of the hand, the open end of the stem dipping in a vessel of water as in Fig. 40. Results?

d. Explain the results noticed in this experiment.

Experiment 62. Freezing Mixtures.

Apparatus. — A small metal beaker; thermometer; salt; ice in small pieces, or ice shavings; a test-tube fitted with a one-hole rubber stopper in which is inserted a glass tube about 10 cm. long and 1 mm. bore; glass tumbler; Bunsen burner.

Directions. — *a.* With the beaker about one-fourth full of water at the temperature of the room or lower, stir the water and record its temperature; also that of the salt. These should agree. Gradually place in the water about a teaspoonful of the salt, stirring slowly with the thermometer. Note the temperature of the solution. What effect, if any, would the stirring have on the temperature? What, then, must have produced the change noticed?

b. Fill the metal beaker with mixed ice and salt, using about twice as much ice as salt. Stir carefully with the thermometer until the mercury column has come to rest, then record the temperature. Change this reading to Fahrenheit. Which melts the faster, the mixed ice and salt, or ice alone? If not certain, take two small pieces of ice of about the same size, sprinkle salt on one, and notice which one melts the faster. What is the cause of the low temperature noticed in *a*? in *b*? Where did the moisture on the outside of the beaker come from?

c. Fill the test-tube with cold water. Insert the stopper and tube, allowing *no air bubbles to remain.* See also that the glass tube contains no air. Place it in the tumbler and pack with the mixed ice and salt. Allow it to remain several minutes, watching carefully the column of water in the glass tube. Result? This part, *c*, illustrates the principle underlying the manufacture of ice cream. Now remove the test-tube, and without disturbing its contents or its connections wipe it *dry* and heat carefully in the Bunsen flame. Result? Explain all phenomena noticed.

Experiment 63. The Dew Point.

Apparatus. — A calorimeter (an aluminum beaker will do); a thermometer; ice or snow; salt if necessary.

Directions. — *a.* Rub the outside of the calorimeter till it is bright. Fill it about half full of water. Gradually cool the water by adding ice or snow, watching the outside of the beaker after each addition and *continually* stirring the contents with the thermometer. As soon as a mist *begins* to form on the bright surface near the bottom of the calorimeter, cease adding ice and note accurately the temperature. If unable to produce the desired result, add a little salt with the ice.

b. It is probable that the temperature thus observed will be a little below the **dew point** (true dew point). Therefore remove any remaining pieces of ice and warm the water a little by making *small* additions of water at the temperature of the room. Note the temperature at the moment the mist begins to disappear. This temperature will probably be a little higher than the true dew point, which can be found by taking the mean of the two observed temperatures in *a* and *b*.

NOTE. — If a thick layer of moisture forms on the beaker before the warming process is begun, it should be wiped off and a thin layer allowed to form.

c. Record the temperature of the room, the temperature out of doors, and the state of the weather.

d. Define dew point from your observations in this experiment.

Experiment 64. To Find the Coefficient of Linear Expansion of a Solid.

Reference. — Hall & Bergen's Physics, pp. 358–363.

Preliminary. — When a rod of any material is heated 1° C., it expands a certain amount. This expansion (in mm.) divided by the original length of the rod (in mm.) is called the **Coefficient of Linear Expansion** for that substance. (Both must be stated in the *same* denomination, but not necessarily in mm.)

In the following work it is very important to determine *accurately* the change of temperature and the expansion of the rod.

Apparatus. — A Linear Expansion Apparatus, with electric connection as directed in Appendix, p. 275; a boiler (Fig. 48); a retort stand; a Bunsen burner; a meter stick; a thermometer; a tumbler; two pieces of rubber tubing about 50 and 10 cm. long, respectively.

Directions. — *a.* Fill the boiler about one-third full with water and place the lighted Bunsen burner under it, all outlets except tube *B* being closed. Measure and record the length of the brass rod.

b. Fit the thermometer in a one-hole stopper to the middle opening of the tube of the Expansion Apparatus so that its bulb will be close to the rod. Place the tube on the rack, one end of the brass rod inside, pressing against the screw in the upright, and the thermometer supported by the retort stand. (Not shown in the figure.) Slip the shorter piece of rubber tubing over the outlet tube of the Expansion Apparatus, and lead it to the tumbler which is to receive the condensed steam. The tumbler should not rest on the apparatus, as heat from it may cause the apparatus to warp somewhat. The longer rubber tube should be attached to the inlet tube.

Caution. — When ready to begin *c* do not allow the apparatus to be moved in any manner until the work is finished, except for measuring with the micrometer in *e*.

c. Turn the micrometer screw until its point just comes in contact with the rod. The exact instant of contact will be indicated by a click from the sounder. The ends of the rod may be beveled, or some other precaution taken to secure contact at the same point in each measurement. Record the reading of the micrometer. Then turn the screw back through two or three revolutions so as to allow for the expansion of the rod.

d. Note the temperature of the rod as indicated by the thermometer. Now connect tube *B* of the boiler with the longer piece of rubber tubing, as in Fig. 45, so that steam shall pass through the apparatus.

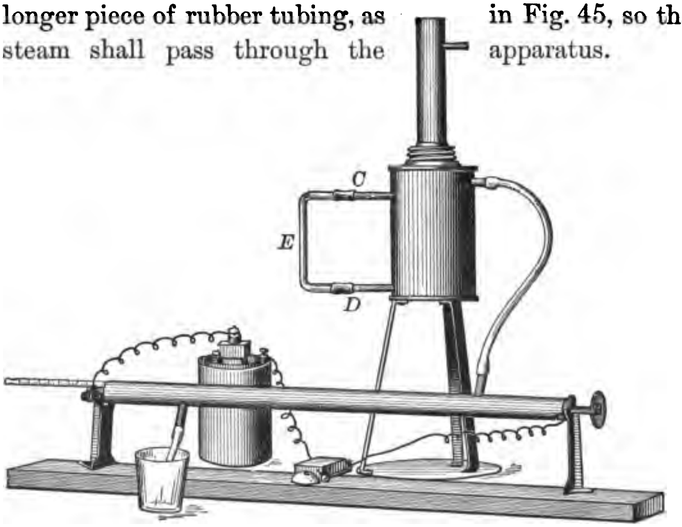

Fig. 45. — Linear Expansion Apparatus.

e. Allow the steam to pass through until the mercury column in the thermometer becomes stationary. Then turn the micrometer screw until contact is indicated by the sounder as before. Note and record the temperature, or, better, compute the boiling point as in Exp. 58, *c*. Read the micrometer and record results in the following table:

Length of Rod (in mm.)	Temperature		Micrometer Reading		Increase in Temperature	Expansion (in mm.)	Expansion for 1° C.
	1st	2d	1st	2d			

Expansion per degree per unit of length, that is, *coefficient of linear expansion* (found by dividing the last column in the above table by the first) . . . .

Accepted coefficient of linear expansion of brass (see Appendix, p. 306) . . . .

Error . . .. % of error . . . .

Experiment 65. To Determine the (Apparent) Coefficient of Cubical Expansion of Mercury.

Apparatus. — A thermometer; a retort stand with clamp, ring, and wire gauze; a 1000 cc. beaker or flask; a glass tube of uniform bore about 25 cm. long and 1 mm. interior diameter, closed at one end, with about 12 cm. of mercury in the closed end; a Bunsen burner; two rubber bands.

NOTE. — For method of placing the mercury in the tube see Exp. 35, Note 3. To test the tube as to uniformity of bore, proceed similarly to Exp. 57, Note 3.

Directions. — *a.* Fasten the tube containing the mercury to the thermometer by means of the rubber bands, so that the closed end of the tube shall be even with the lowest division line of the thermometer scale. Cool the apparatus with cold water (ice water if available) until the temperature is as near 0° C. as possible. Note the temperature. Then, *while the apparatus is immersed in the water*, measure the length of the mercury column in the tube, using the scale of the thermometer for this purpose. The thermometer stem, being graduated in equal divisions, affords a convenient method of making this measurement. (This, of course, is quite different from the ordinary use of a thermometer, though it is also to be used for its ordinary purpose in *b.*)

b. Now place the beaker, filled with water, on the wire gauze on the retort stand. Support the thermometer and tube of mercury by the retort stand clamp so that the top of the mercury column shall be just below the surface of the water. Heat the water with the Bunsen flame until it boils. Remove the flame and immediately record the temperature and the length of the mercury column as before.

c. Since the bore of the tube may be considered to be uniform, the increase in *volume* of the mercury will be in the same proportion as its increase in *length.* This expansion (or increase), of volume, divided by the observed change in temperature gives the expansion per degree. The **apparent coefficient of expansion** is the expansion per degree divided by the initial volume of the mercury as obtained in *a.* This is called the *apparent* expansion, because the expansion of the glass has not been taken into consideration. The *absolute* (true) coefficient of cubical (volume) expansion may be obtained by adding to the apparent coefficient the coefficient of cubical expansion of the glass. This has been found to be 0.0000258. Compare the final result with that given in the Appendix, p. 306, and note the amount of error and percentage of error.

d. Record results in the following table:

Temperature		Volume of Mercury (Length)		Increase in		Expansion for 1° C.	Coefficient of Apparent Expansion	Coefficient of Expan. of Glass
1st	2d	1st	2d	Temperature	Volume			
								0.0000258

Absolute coefficient of cubical expansion of mercury
as here obtained . . . .
Accepted coefficient of cubical expansion of mercury ....
Error . . .. % of error . . . .

Experiment 66. To Determine the (Apparent) Coefficient of Cubical Expansion of Air under Constant Pressure.

Apparatus.—A thermometer, *T*, Fig. 46; a glass tube, *AB*, of uniform bore about 25 cm. long and 1 mm. interior diameter, closed at one end and provided with a mercury index, *C*, 1 cm. or less in length, which, when the tube is horizontal and at the temperature

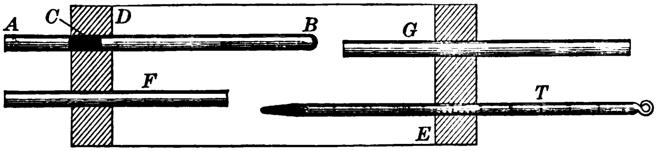

FIG. 46.

of the room, stands at about 15 cm. from the closed end; a shallow trough with a tubulure in one end fitted with a one-hole rubber stopper to contain this tube; a glass or tin tube, *DE*, about 3 cm. in diameter and 25 cm. long, closed at each end with a two-hole rubber stopper; two pieces of glass tubing, *F* and *G*, each about 10 cm. long, fitting these stoppers; a piece of rubber tubing about 50 cm. long to fit one of the short glass tubes; a boiler to supply steam.

NOTE 1. — The mercury index may be placed in the tube as directed in Exp. 35, Note 3. Make the index short. For accurate work the amount of change in the length of the index must be noted. To test the tube as to uniformity of bore, proceed similarly to Exp. 57, Note 3.

NOTE 2. — Hold the tube horizontally and vertically to see if there is any difference in the position of the index. Make all the following measurements with the tube horizontal.

Directions. — *a.* Remove the tube *AB* from the apparatus of Fig. 46 and measure the length of the mercury index *C*, and also the total interior length of the tube, estimating to tenths of a millimeter. In the latter measurement allowance must be made for the taper at the closed end, unless it agrees closely in shape with that of the end of the mercury index.

b. Place this tube in a horizontal position through the stopper in the trough so that the outer end of the index is just visible and surround it with finely broken ice. Allow the tube to remain in this position for a few minutes, until the index ceases to move. Tap the tube gently with a pencil, in order that the index may more readily assume its correct position. Without moving the tube, measure the distance from its open end to the index and calculate the length of the air column enclosed by the index.

c. Remove the tube from the trough and arrange the apparatus as in Fig. 46. Be sure that the joints are tight; then, placing the apparatus in a *horizontal* position, connect it with the boiler by means of the rubber tube and pass a current of steam through it. As the enclosed air expands push in the tube so as to keep the outer end of the index even with the face of the stopper. Tap the tube occasionally, in order to aid the movement of the index.

d. When the index ceases to move, showing that expansion has ceased, record the temperature, corrected, or computed as in Exp. 58, *c*; measure the distance from the index to the open end of the tube and compute the length of the enclosed air column as in *b*.

e. As in Exp. 65, *c*, since the bore of the tube may be considered to be uniform, the increase in *volume* of the enclosed air column will be in the same proportion as its increase in *length*. This expansion (or increase) of volume divided by the observed change in temperature gives the expansion per degree. **The apparent coefficient of expansion** is the expansion per degree divided by the initial volume of the enclosed air as obtained in *b*. This is called the *apparent* expansion, because the expansion of the glass and mercury have not been taken into consideration. The **absolute (true) coefficient of cubical (volume) expansion** may be obtained by adding to the apparent coefficient the coefficients of expansion of the glass and mercury. This latter, however, may be neglected in this work, as the small amount of mercury used makes the error due to it very slight. The coefficient of expansion of glass has been found to be 0.0000258. Compare the final result with that given in the Appendix, p. 306, and note the amount of error; also find the percentage of error.

f. Make three trials if time permits and record results as follows:

No. of glass tube . . . .
Length of index . . . . mm.
Distance from index to open end of tube at 0° C. . . . .
Length of enclosed air column at 0° C. . ...
Final temperature as in *d* . . . . °
Distance from index to open end of tube at .... ° C. . . . .
Length of air column at .... ° C. . . ..
Amount of change in temperature . . .. °
Expansion of air column for .... ° (the total change in temperature) .... mm.
Apparent coefficient of cubical expansion of air . . . .
Coefficient of expansion (cubical) of glass 0.0000258
Absolute coefficient of cubical expansion of air . . . .
Error . . .. % of error . . ..

Experiment 67. To Determine the Latent Heat of Fusion of Ice; that is, How Much Heat is Necessary to Melt 1 g. of Ice?

Apparatus. — A calorimeter of thin metal; a supply of warm water; blotting paper; a thermometer; a retort stand; a Bunsen burner; wire gauze; small lumps of clean ice; a balance and weights.

Note 1. — If the ice is brought in from out of doors in cold weather, it may be colder than 0° C. In that case time must be allowed for it to reach the melting point before using.

Directions. — *a.* Rub the calorimeter till it is bright. Weigh carefully the *dry* calorimeter.

b. Fill the calorimeter about two-thirds full of water warmed to about 40° C., and weigh with the same degree of accuracy as in *a.*

c. Place the calorimeter containing the water on the piece of blotting paper well back on the table so that there may be plenty of room, and do not touch it again with the hands until *f* is reached. Stir the water thoroughly with the thermometer and record its present temperature, which should now be about 35° C. (estimating tenths of a degree). Quickly cool the thermometer with ice to about 5° C.

d. *Immediately* add enough ice in small lumps to almost fill the calorimeter. The ice must be wiped dry with a cloth just before being added. Stir the mixture of ice and water gently but continually with the previously cooled thermometer, and do not remove it from the liquid till *e* is finished.

e. Just as the last bit of ice is melted note the temperature accurately. If the ice is not all melted by the time the water has been cooled to about 5° C., dip out the remaining pieces, taking as little water as possible, and throw them away. It is important that the final temperature be as much *below* that of the room as the temperature in *c* was *above* it. In this way the influence of the temperature of the room on the result will be equalized, and therefore may be disregarded. If these results were not obtained, repeat the work.

f. Now remove the thermometer with as little water as possible. Weigh the calorimeter and the water it contains to determine the weight of ice used.

NOTE 2. — Observe that not only was the ice melted but the resulting water was also warmed to the final temperature. In order to produce these two results heat had to be furnished by the warm water and calorimeter. This left them just so much cooler. Evidently the same amount of heat lost by the water and calorimeter was gained by the ice and the water from the melted ice. Part of the heat was used in melting the ice; part in warming the water which resulted from melting the ice. It now remains to determine upon a *unit of heat.* We will adopt for our unit that amount of heat which will raise the temperature of 1 g. of water 1° C. We will call this a **calorie.** If one calorie will heat 1 g. of water 1° C., will one calorie be given out by 1 g. of water in cooling 1° C.? In determining the amount of heat given out by the calorimeter, note that if it is made of brass 1 g. of it in cooling 1° C. will give out only 0.09 of a calorie. This number, 0.09, is called the **specific heat of brass.** If the calorimeter is of some other substance, of course *its* specific heat must be considered.

g. Tabulate results as follows:

Weight of the calorimeter . . . .
Weight of calorimeter and water . . . .
Weight of water used . . . .
Weight of calorimeter, water, and ice . . . .
Weight of ice used . . . .
Temperature of water at first . . . .
Temperature of ice . . . .
Final temperature of mixture . . . .
No. of degrees water and calorimeter were cooled . ...
No. of degrees water from the melted ice was warmed ....
No. of calories given out by water and calorimeter . ...
No. of calories received by the ice and its water
(same as in last line) . . . .
No. of these latter calories required to warm the
ice water . . . .

No. of same calories remaining to melt the ice (to have melted it) . . . .
No. of calories required, therefore, to melt 1 g. of ice ....
Latent heat of fusion of ice obtained (see name of this experiment) . . . .
Accepted latent heat of fusion of ice (see Appendix, p. 301) . . . .
Error . . . . % of error . . . .

Experiment 68. To Determine the Latent Heat of Vaporization of Water; that is, How Much Heat is Given out in Condensing 1 g. of Steam to Water?

Apparatus. — A boiler (Fig. 43) with a rubber tube about 50 cm. long attached to tube *B*; a Bunsen burner; a beaker of warm water; a calorimeter; a thermometer; a "trap" (see Fig. 47), designed to retain the water produced by the steam that condenses before reaching the water in the calorimeter during the experiment; a balance and weights; a piece of glass tubing about 20 cm. long for a delivery tube, to be connected with the trap by a piece of rubber tubing.

NOTE 1. — Use plenty of heat, in order that the steam shall pass rapidly into the calorimeter. This will lessen the error.

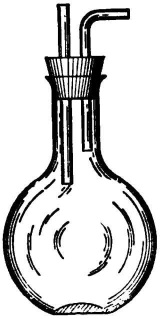
FIG. 47. — "Trap."

Directions. — *a.* Weigh carefully the calorimeter.

b. Close the openings *A* and *F* of the boiler and connect the trap and glass delivery tube so that steam may pass from the boiler successively through tube *B*, the long rubber tube, trap, and delivery tube. Heat the water in the boiler until a vigorous stream of steam issues from the delivery tube. While the water is heating fill the calorimeter to within about 3 cm. of its top with water, the temperature of which is between 0° and 5° C. Weigh the calorimeter and water as accurately as in *a* and calculate the weight of the water. Interpose some sort of a screen between the calorimeter of water and the gas flame. Note accurately the temperature of the water in the calorimeter, which should now be about 15° below the temperature of the room, and *immediately* wipe the end of the delivery tube dry and plunge it nearly to the bottom of the water in the calorimeter. Explain the noise. If the boiler leaks, raise the delivery tube somewhat.

c. Warm the thermometer to about 15° above the temperature of the room by placing it in a beaker of warm water. Now place the warmed thermometer in the calorimeter, using it and the delivery tube as stirring rods, and stir continually the water in the calorimeter. Do not remove either of them from the water till *c* is finished. When the temperature has risen to about 15° above the temperature of the room (see Exp. 67, *e*), remove the delivery tube with as little water as possible. Note the temperature immediately and remove the thermometer with as little water as possible.

d. Weigh the calorimeter (dried on the outside, if necessary) and water to obtain the weight of steam condensed, which, of course, is now in the form of water.

e. Determine the temperature of the steam by reading the barometer and computing the boiling point (see Exp. 58, *c*). Or determine its temperature by a thermometer (*corrected*).

NOTE 2. — The water in the calorimeter has now received a certain number of calories of heat. These must have come from the steam, part of them being given out by the steam at the boiling point, as it is condensed to water at the same temperature, and part by the resulting water, as it cooled to the final temperature.

The influence of the thermometer, the air of the room, etc., on the result is equalized as above directed, and may be disregarded.

The amount of heat given out by 1 g. of the steam, as it changes to the form of water at the same temperature, is called the **latent heat of steam,** or the **latent heat of vaporization of water.**

f. Tabulate the results as follows:

Weight of calorimeter . . . .
Weight of calorimeter and water . . . .
Weight of water alone . . . .
Weight of calorimeter, water, and steam . . ..
Weight of steam alone . . . .
Height of barometer . . . .
Computed temperature of steam . . . .
Initial temperature of water . . . .
Final temperature of mixture . . . .
No. of degrees calorimeter and water were warmed . . . .
No. of degrees steam was cooled after being condensed . . . .
No. of calories received by water and calorimeter (see Exp. 67, Note 2) . . . .
No. of calories given out by the steam and its water of condensation . . . .
No. of these last calories furnished by the water of condensation in cooling from the computed temperature of the steam to the final temperature . . . .
No. of same remaining to have been furnished by the condensing steam . . . .
No. of calories given up by the condensation of 1 g. of steam . . . .

Latent heat of vaporization of water obtained (see name of this experiment) . . . .
Accepted latent heat of vaporization (see Appendix, p. 301) . . . .
Error . . . . % of error . . . .

Experiment 69. To Determine the Specific Heat of Solids.

Apparatus. — A balance and weights; a thermometer; a beaker of boiling water; a retort stand; a metallic ball (or cylinder), about 3 cm. in diameter, provided with a hole or hook for attaching a thread; a calorimeter; thread; a Bunsen burner.

Directions. — *a.* Weigh the ball with the thread attached to it. Suspend it from the retort stand so that it shall be immersed in the boiling water.

b. Weigh the *dry* calorimeter.

c. Fill the calorimeter about three-fourths full of water at a temperature a little (2° or 3°) below that of the room. Weigh the calorimeter and contents.

d. Record the temperature of the boiling water (see Exp. 58, *c*).

e. Place the calorimeter where it is not exposed to external influences of heat or cold, and take the temperature of the water to tenths of a degree.

f. Immediately transfer the ball to the calorimeter, being careful to transfer as little water as possible with it. Move the ball around near the bottom of the water and stir carefully with the thermometer also.

g. Record the highest temperature of the water (which will also be that of the ball).

h. Record results in the following form:

Mass of the ball (or cylinder) . . . . m

Mass of the calorimeter . . . . m'

Mass of water taken . . . . m''

Mass of the calorimeter and water . . .. $m'+m''$

Temperature of the boiling water and ball . . . . t

Temperature of the water in the calorimeter at first . . . . t'

Highest temperature of the water and ball in the calorimeter . . . . t''

Change of temperature of the ball . . .. $t-t''$

Change of temperature of the water and calorimeter . . . . $t''-t'$

Specific heat of the material of which the calorimeter is composed (see Appendix, p. 307) . . . . S

Water equivalent of the calorimeter (see Note 1 below) . . . . $m' \times S$

Specific heat obtained according to the directions in *i* below, for the material of which the ball is composed x

Accepted specific heat for this material (see Appendix, p. 307) . . . .

Error . . .. % of error . . ..

i. It is evident that we have a right to assume that the heat given out by the ball in cooling was used in warming the water and the calorimeter. (Some, of course, is lost to the air, etc., but this will be neglected. The warmer the room, the less this error will be.) Each of these two equal quantities of heat is equal to the mass of the body under consideration, multiplied by its **specific heat**, multiplied by its change in temperature, *i.e.*, the mass of the ball (m) multiplied by its specific heat (call this x), multiplied by its change in temperature ($t - t''$), would just equal the mass of the water (m'') multiplied by its specific heat (which is 1), multiplied by its change in temperature ($t'' - t'$) (this is neglecting the calorimeter).

The specific heat of water, since water is considered as the standard, is 1. Call the specific heat of the ball that is here to be determined x, and that of the material of the calorimeter S, as in the above form. Then m times x, times ($t - t''$), equals m'' times 1, times ($t'' - t'$), plus m' times S, times ($t'' - t'$), or, in the form of an equation:

$$mx\,(t - t'') = m''1\,(t'' - t') + m'S\,(t'' - t'),$$

from which

$$x = \frac{m''\,(t'' - t') + m'S\,(t'' - t')}{m\,(t - t'')}, \text{ or}$$

$$x = \frac{(m'' + m'S)\,(t'' - t')}{m\,(t - t'')}.$$

Substituting in this equation the proper numerical values, as obtained in the above work, the required value of x may be determined.

NOTE 1.—The **water equivalent** (thermal capacity) of the calorimeter is obtained by multiplying its specific heat by its mass; this product represents the number of grams of water having the same *heat capacity* as the calorimeter. In more accurate work it is necessary to take the water equivalent of the thermometer and thread into consideration also.

NOTE 2.—Shot may be used in place of the metallic ball. In that case the shot should be heated dry in the "dipper" of the boiler, the dipper being subjected only to the heat of the steam from the boiler. Stir the shot thoroughly with the thermometer while heating, and read the temperature immediately before transferring the shot to the water as in *f* above.

Experiment 70. Temperature Curves of Liquids, or Law of Cooling. Specific Heat of Turpentine.

Apparatus. — Water; turpentine or some other suitable liquid whose specific heat is to be determined; a retort stand; a Bunsen burner; a calorimeter or metal beaker; wire gauze; a thermometer; a balance and weights; a piece of asbestos or blotting paper about 10 cm. square.

Directions. — *a.* Heat 200 g. (or cc.) of water in the calorimeter to a temperature of about 95° C., and note the temperature of the room.

b. Stand the calorimeter on the asbestos. Suspend the thermometer with its bulb in the middle of the water and take the temperature to tenths of a degree. Do not stir the water nor disturb it in any way during the remainder of the work.

c. Observe the temperature at intervals of one-half minute for the first five readings, and then at intervals of one minute for at least 30 minutes, or until the water nearly reaches the temperature of the room.

d. Repeat the above, using the same weight of turpentine.

Caution.—The vapor of turpentine is very inflammable. Place the calorimeter of turpentine on the wire gauze on a ring of the retort stand while heating the turpentine. Heat it no higher than the water was heated.

e. Record results in the following form:

TEMPERATURE OF THE ROOM .... ° C.

No. of Observations	WATER				TURPENTINE			
	Time by the Clock	Time from First Reading	Observed Temperature	Observed Temperature Minus that of the Room	Time by the Clock	Time from First Reading	Observed Temperature	Observed Temperature Minus that of the Room
1								
2								
3								
4	etc. to	30 obser	vations.					

f. Plot a "curve of cooling" for each liquid, both curves from the same origin, using times as abscissas and the differences of temperatures as ordinates. What relation does each of these curves show between the time and the change in temperature? This relation is called **Newton's Law of Cooling.**

g. What do the curves show as to the rate of cooling of the two liquids?

h. Determine the specific heat of the turpentine. To do this, divide the time required to cool the turpentine, say 20 degrees, by the time required for the water to cool through precisely the same 20 degrees. Why is this the specific heat of turpentine? How does the specific heat of a substance affect the time required for it to cool?

ELECTRICITY.

MAGNETISM.

Experiment 71. Magnetic and Non-Magnetic Substances.

Caution. — Handle magnets carefully, as a blow or a fall is liable to weaken them. Magnets should never be left with their "like" ends adjacent, for they are liable in that case to lose their strength. They should be left instead, as the bar magnets are shown in Fig. 48, with "unlike" ends adjacent and with "keepers" of soft iron, *A* and *B*, joining their ends.

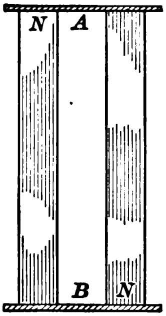

FIG. 48.

Apparatus. — A piece of watch spring (or knitting needle); a mixture of bits of brass, copper, wood, paper, nickel, pith, and iron filings; a bar magnet (or a horseshoe magnet).

Directions. — *a.* Put some of the mixture on a sheet of paper and stir it with the piece of watch spring. Result?

b. Rub the watch spring several times along one end only of the magnet, always rubbing the spring on the magnet in the one direction, as shown in Fig. 49, removing the spring from the magnet at the end of each stroke. Again stir the mixture. Result? Why?

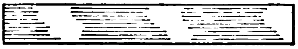

FIG. 49.

c. The phenomena noticed are due to the magnetization of the watch spring, which has been brought about by the bar magnet. The watch spring is now a magnet. What substances were attracted or held by the magnet when touched by it? Such substances are called **Magnetic Substances.** Substances unaffected by the magnet are called **Non-magnetic Substances.**

NOTE. — Iron filings may be readily removed from magnets with a brush.

Experiment 72. To Determine whether Magnetic Attraction can be Produced without Contact.

Apparatus. — A bar magnet; iron filings; a sheet of paper; a piece of window glass about 6 in. × 8 in.; similar pieces of zinc, copper, iron, wood, mica, and brass.

Directions. — *a.* Place the filings on the paper, and bring one end of the magnet *near* the filings. Result?

b. Lay the magnet on the table, and, holding the paper of iron filings in both hands, slowly move it back and forth just above the magnet. Result?

c. Place the filings on the window glass, and slowly pass the magnet under the glass, holding it as near as possible. Result?

d. What is your conclusion as to whether contact is necessary for magnetic attraction?

e. Repeat *c*, using in succession the pieces of zinc, iron, and copper in place of the glass.

f. Which of these materials cut off the magnetic action from the filings? Such substances are called **magnetic screens,** and are used for the purpose indicated by their name.

Experiment 73. Polarity and Magnetic Strength.

Apparatus. — Fine iron filings; a magnet; a sheet of paper; an unmagnetized piece of watch spring; a glass or other non-metallic dish, with water.

Directions. — *a.* Touch the watch spring to some iron filings to make sure that it is not magnetized. Float the watch spring on the water in the glass dish, using a piece of flat cork if needed, though with care the cork is unnecessary. When it has come to rest, carefully turn it around until it is at right angles to its first position. Notice whether it remains nearly stationary or not. Repeat until certain of result.

b. Now magnetize the watch spring and repeat *a.* Result?

c. Lay the magnetized watch spring on the paper and sprinkle it with iron filings. Pick it up carefully. Notice whether the filings cling uniformly along the entire length of the magnet. Strip off the filings and repeat. Make a sketch showing the results noticed. In what part of the magnet are the places of greatest magnetic strength located? These places of greatest magnetic strength are called the **poles** of a magnet.

d. Call the end of the magnet which points toward the north the North-Seeking (N.-S.) pole, the one which points toward the south the South-Seeking (S.-S.) pole. Mark the North-Seeking pole of the magnet and save it for the following experiments.

Experiment 74. The Magnetoscope.

Apparatus. — A magnetoscope (see Appendix, p. 276); a soft iron rod about 8 or 10 cm. long; the magnetized watch spring of the last experiment.

Caution. — In all magnetic work, remember that the proximity of masses of iron and steel, such as gas pipes, keys, or knives, will invalidate the work. The greater the mass of such bodies, the greater will be their effect. Be very sure that no iron or steel article is within a meter of the magnetic needle. (See Exp. 79, a.)

Directions. — *a*. Allow the needle of the magnetoscope to come to rest in a north-and-south position. Hold the soft iron rod *horizontally*, at *right angles* to the north-and-south position of the needle and some distance away from it. Slowly bring one end of the rod toward the North-Seeking pole of the magnetoscope, as in Fig. 50, where *M* is the needle of the magnetoscope and *R* the soft iron rod. Result? Repeat with the other end of the rod. Result?

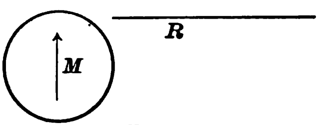

FIG. 50.

b. Repeat *a* with the South-Seeking pole of the magnetoscope. Result?

c. Repeat *a* and *b*, using the magnetized watch spring in place of the soft iron rod.

d. How does the action when the soft iron rod is used differ from that when the magnet is used?

e. State how to detect the presence of magnetization in a body by means of the magnetoscope.

Experiment 75. Law of Magnetic Action.

Apparatus. — A magnetoscope; a magnetized watch spring.

NOTE. — In the last experiment we learned that a magnetoscope can be used to detect the presence of magnetization. Why is *repulsion* and not *attraction* the proper test for the presence of magnetization in a body?

Directions.—*a.* Slowly bring one pole of the magnetized watch spring toward one pole of the magnetoscope. Make the following tests, recording the results:

POLE OF MAGNET USED	POLE OF MAGNETOSCOPE	EFFECT
North-Seeking	North-Seeking	
North-Seeking	South-Seeking	
South-Seeking	South-Seeking	
South-Seeking	North-Seeking	

b. From these results derive the law for the action of magnetic poles upon each other.

Experiment 76. Effect of Breaking a Magnet.

Apparatus. — A magnetoscope; a magnetized watch spring; iron filings; a small test-tube with stopper.

Directions. — *a.* Determine and mark the North-Seeking pole of the magnet. Break or cut it into two pieces. Roll each part in iron filings. Result?

b. Strip off the filings and test each piece for polarity with the magnetoscope. What is learned?

c. Mark the two North-Seeking poles; break each piece again and test as before. Result?

d. Now lay the pieces on a sheet of paper in their original positions and make a sketch showing the present position of the poles.

e. Suppose this dividing process to be continued until the smallest possible physical unit is reached. This unit would be a single molecule. What would be the condition of each of the molecules thus separated?

f. Half fill the test-tube with iron filings, insert the stopper, and cause the filings by shaking to reach from end to end of the tube when held horizontally. Keeping the tube in this position, treat it as though it were an iron rod and test it for polarity.

Caution. — Be careful not to shake the filings in the slightest degree till directed to do so in *h*.

g. Magnetize the tube of filings as in Exp. 71, *b*, holding the tube stationary and moving the magnet. Being careful not to disturb the filings, test for polarity.

h. Shake the tube (disturb the filings) and again test for polarity.

i. Judging from the above experiment, how are the poles of each individual molecule of a magnet arranged with reference to the poles of neighboring molecules?

Experiment 77. Arrangement of Poles during Magnetization.

Apparatus. — Several pieces of unmagnetized watch spring; a bar magnet; a magnetoscope.

Directions. — *a.* Rub one end of a piece of watch spring four or five times across the North-Seeking pole of the magnet. Test this end of the watch spring for polarity. Repeat with two or three other pieces. Record results.

b. Repeat *a*, using the South-Seeking pole of the magnet and a new piece of watch spring.

c. State your conclusion as to the relative positions of the poles of the magnet used, and of the magnet produced, during magnetization. Show this by a sketch.

Experiment 78. To Determine whether Polarity can be Reversed.

Apparatus. — A bar magnet; a watch-spring magnet; a magnetoscope.

Directions. — *a.* Lay the bar magnet on the table. Placing a finger on the watch-spring magnet, slowly slide its North-Seeking pole toward the North-Seeking pole of the large magnet until they touch. Let it remain for a minute or so, then remove and test for polarity.

b. Repeat several times until certain of results.

c. Explain the results noticed.

Experiment 79. Magnetization by Induction.

Apparatus. — A soft iron rod about 10 cm. long; iron filings; a bar magnet; a horseshoe magnet; thread of silk fiber.

NOTE. — Soft iron is very difficult to obtain. Therefore the results of this experiment may be somewhat unsatisfactory.

Directions. — *a.* Test the iron rod for magnetization with the filings. If more than a trace of magnetization is shown, reject the rod and select another.

b. Place the rod in a paper stirrup and suspend it by a silk fiber, or by several fibers if one is not strong enough, so that it shall be over and near the poles of a strong horseshoe magnet that is supported in a vertical plane with its South-Seeking pole toward the north. After the rod is at rest *slowly* approach one end of the suspended rod with the North-Seeking pole of the bar magnet, as in Fig. 50. Result? Repeat with the other end of the rod and the same pole of the bar magnet. Result?

c. Repeat *b*, using the South-Seeking pole of the bar magnet. Does the rod now act as though it were magnetized?

d. Reverse the rod and repeat *b* and *c*.

e. Try the rod with the filings once more. Is it magnetized? Place one end of the rod in the iron filings and bring a pole of the bar magnet *near* the other end of the rod *without touching it.* Raise the apparatus from the filings without disturbing the relative positions of the rod and magnet. Is the rod now magnetized? Remove the magnet, holding the rod perfectly quiet and observe for a few moments. Result? Reverse the rod and repeat.

f. Test the rod alone again as in *a.* Is it now magnetized? If a rod of soft iron has magnetic properties while thus in use, it is called an **induced magnet.**

g. From the results obtained in *b* and *c* what is learned as to the position of the poles in an induced magnet with reference to those of the inducing magnet?

h. Define an induced magnet.

Experiment 80. The Magnetic Field and Lines of Force.

Apparatus. — Three sheets of rapid printing blue print paper the size of the notebook used; two bar or horseshoe magnets; two rulers or pieces of wood the thickness of the magnets; iron filings; a small sieve (an ordinary pepper-box). Water tank or other large vessel of water for washing the blue prints.

Caution. — As the blue print paper is sensitive to the light, keep it in the dark until the rest of the apparatus is arranged. Try a several times with ordinary paper for practice before attempting to use the blue print paper, as with this, one must work rapidly. Keep

the paper free from folds or wrinkles. If it is inclined to "curl" hold it in place with non-magnetic weights.

Directions. — *a.* Lay a magnet on the table between the two rulers. Cover it with the sheet of blue print paper, colored side up. Mark on the paper the position of the respective magnet poles. With the sieve sprinkle the iron filings evenly on the paper from a height of about 50 cm. It is best not to use too many filings. Tap the paper lightly with a pencil until the outline of the magnet is very distinct and the lines of iron filings can be distinctly seen radiating from the poles.

NOTE 1. — These lines of filings indicate the direction of some of the **Lines of Force** which extend through the **Magnetic Field** of the magnet.

b. Allow the apparatus to remain untouched for a period of from 5 to 20 minutes, according to the light, or until the uncovered portion of the paper has changed color considerably. Then pour off the filings and thoroughly wash the paper in the water tank. Hang it up to dry. A permanent print will remain. When dry insert it in your notebook.

c. While waiting for the "action" in *b*, investigate the field as follows: Repeat *a* using a sheet of ordinary paper. Suspend a very short magnet by a fine thread, determine its polarity, and carrying it about, as near the filings as possible without touching them, see if it seems to take any definite position with reference to the lines of force.

d. Repeat *a* and *b*, using the two magnets and placing them side by side about 5 cm. apart with like poles opposite each other.

e. Repeat *d* with unlike poles opposite each other.

f. Define Lines of Force and Magnetic Field.

NOTE 2. — The best quality of blue print paper can be obtained in ten yard rolls one yard wide for about eighty cents per roll.

Experiment 81. Magnetic Effect of the Earth.

Apparatus. — A magnetoscope; a narrow strip of ordinary tinned iron about 10 × 1 cm.

Directions. — *a.* Test the tinned strip for magnetization. Result?

b. Hold the strip horizontally, east and west, and bend it to and fro smartly with the fingers at various points throughout its length; *i.e.*, disturb it mechanically. Test as before. Result?

c. Repeat *b* holding the strip vertically. Test as before. Result? If magnetized which pole is at the lower end?

d. Repeat *c* inverting the strip; *i.e.*, making what was the upper end, the lower, and test as before. Result?

e. Repeat *b.* Result?

f. What does this experiment show as to the magnetic effect of the earth?

ELECTROSTATICS.

Experiment 82. The Production of Electrification by Friction.

NOTE. — A dry, cold day is necessary for obtaining good results in Exps. 82–86 inclusive. The apparatus must be clean and *dry*. The rods and cloths should be warm. The rods are to be held by the same end in each trial. It is well to mark the end to be held in the hand. When the heart of some kinds of plants is very light it is called **pith.** Cornstalk (*dry*) is a good example; so is the sunflower. Use only the heart. Make the pith ball about 6 mm. in diameter. Trim it very smoothly with a sharp knife and finally roll very lightly between the fingers.

Apparatus. — A piece of hard glass rod or tubing about 30 cm. long and 1 cm. diameter; a similar piece of vulcanite or a rod of sealing wax about 30 cm. long and 2 cm. square; natural silk fiber or a raveling from fine white silk cloth if the fiber is not available, the raveling will not twist as silk thread does; one piece each of the best quality of silk and flannel about 20 cm. square; bits of dry tissue paper, sawdust, bran, or pith; a pith ball.

Directions. — *a.* Bring a glass rod near some small bits of tissue paper, pith, sawdust, or bran. Try a vulcanite rod in the same way. Result?

b. Rub one end of the glass rod with silk and repeat *a.* It may be well to use several thicknesses of the silk, or place a piece of flannel between the silk and the hand, if the air is damp. Does glass treated in this manner show very different properties from glass not so treated? Repeat several times and notice whether dry glass rubbed with dry silk always has the same properties? Result?

c. Repeat *b* with a vulcanite rod rubbed with warm flannel. Result? The peculiar action manifested by these rubbed bodies is due to **electrification** produced by the rubbing.

d. If it has been found that different substances can be electrified by rubbing, the question whether these bodies have the same kind of electrification naturally presents itself. To determine this, suspend a rubbed glass rod in a paper stirrup by a silk fiber (use several pieces of the fiber if necessary) and carefully approach the rubbed end with a second rubbed glass rod. Approach it with a rubbed vulcanite rod. Now suspend a rubbed vulcanite rod in place of the glass and repeat. Results?

e. Suspend the pith ball by a silk fiber about 20 cm. long. Call this an **electroscope.** Be careful to suspend the ball so that it cannot strike or come near any object as it swings. Electrify the vulcanite rod as before and hold it near the pith ball. Notice whether there appears to be any change in the attraction when the ball is allowed to come in contact with the electrified rod. Electrify the glass rod and hold it near the pith ball. Hold the electrified glass rod in contact with the pith ball until the ball is repelled and then notice whether the electrified vulcanite repels it also. Begin again with the rubbed vulcanite rod and repeat till sure of results.

f. After the pith ball has been repelled by either the electrified glass or vulcanite, how does it act toward the other? *Immediately* after the pith ball has thus been repelled, approach it *carefully* with some other convenient object, as a pencil, a pen, the finger, a piece of paper, etc. Notice that the result is the same in each case. What is the result? Have any of these latter bodies been electrified? Such bodies are said to be **neutral** bodies.

g. Is the electrification of the glass of the same nature as that of the vulcanite? Any two substances when thus rubbed together will produce electrification, though in varying degree. Silk and glass give good results; so also do vulcanite and flannel. Use them as directed above. For convenience that kind of electrification which is developed on glass when thus rubbed with silk is called **positive,** and that on vulcanite or sealing wax when rubbed with flannel, **negative.**

h. It was learned in *f* that attraction existed between the electrified pith ball and various unelectrified bodies. Will it be safe then to rely upon *attraction* as the answer to the above question? Why? Will *repulsion* be a safe test? Why? An electrified body is said to be **charged.** How can a pith ball be charged positively? How can one tell whether a charged body has a positive or negative charge?

Experiment 83. Electrification by Conduction.

(*For the Instructor.*)

Apparatus. — Two calorimeters or metal beakers resting on a plate of vulcanite or glass, each provided with a pith ball suspended on a very fine copper wire about 10 cm. long, hung on the edge of the calorimeter. This will be a sensitive electroscope. The ends of the wire should be tipped with sealing wax to prevent leakage. Or use two spherical shells, such as are used on the ends of curtain poles, about 5 cm. in diameter, mounted on short pieces of sealing wax or other insulating material, so that they will be about 12 cm.

high, and a pith-ball electroscope, mounted so that the center of the ball is as high above the table as the centers of the spheres; a vulcanite rod; flannel; pieces of copper, iron, and brass wire, glass tubing, vulcanite, wood, silk thread, leather, paper, paraffine, and sealing wax, each about 20 cm. long; a glass beaker or other insulating support about 10 cm. high.

Directions. — *a.* Place the two shells about 15 cm. apart and charge one from the electrified vulcanite in the same way the pith ball was charged in Exp. 82. It may be necessary to charge the rod, and from it the shell, several times to produce satisfactory results. Determine its kind of electrification with the assistance of the pith-ball electroscope, as was done in Exp. 82.

b. Touch the shell with a finger. Test it now for electrification. Before each of the remaining trials see that the shell charged in *a* is recharged and that the other shell is neutral or discharged.

c. Allow the piece of glass tubing resting on the insulating support to touch both shells at the same time, thus connecting them. Test each shell for electrification as in *a*. Result?

d. Repeat, using the wood, sealing wax, etc. Try also a dry and then a wet silk thread. Record in three columns the results obtained with these materials, placing in one column the **conductors,** in another the **insulators** or **non-conductors,** and in the third the partial conductors.

e. To which class does the human body belong?

f. The second shell is said to be charged from the first by **conduction.** So also was the first shell charged from the vulcanite rod. Is the resulting charge like or unlike the exciting charge?

Experiment 84. Electrification by Induction.

(*For the Instructor.*)

Apparatus. — The two shells used in Exp. 83; two pith-ball electroscopes as made in Exp. 82; vulcanite and glass rods; flannel and silk.

Directions. — *a.* Charge a pith-ball electroscope as in Exp. 82. Test it for electrification. Touch it *for an instant* with a finger and test again. Hold it closely in the hand for a moment and then test again. Is this third result like the second? Why was the second result different from that in Exp. 83, *b*? Why not use rods of metals in place of the vulcanite and glass in Exp. 82? Charge the electroscope again, and charge the second one with the opposite kind of electrification. Charge one of the shells by conduction from the electrified vulcanite rod, and test the shell for kind of electrification, with the pith-ball electroscopes as in Exp. 83.

b. Place the second shell (without touching it with a conductor) about 5 mm. from the charged one. Remove the second shell at least 40 cm. from the first, and test the second for electrification. Result?

c. Again place the second shell about 5 mm. from the charged one, and touch that side of the second farthest from the charged one with the finger, and then remove, first the finger, and then the second shell. Now determine with the electroscopes whether the second shell has a charge, and if so, its kind.

d. If the second shell was electrified in the last operation, discharge it, and recharge the first shell if necessary. With the two shells once more about 5 mm. apart, touch with the finger that part of the neutral shell lying nearest the charged one. Remove the finger and then the charged shell, and determine as in *c* the presence and kind of electrification in the second shell.

e. Hold the electrified vulcanite about 5 mm. from one side of a neutral shell, at the same time touching the shell with the finger. Remove first the finger, and then the vulcanite. Test the shell for electrification, and the kind, if any.

f. Repeat *e*, using a rod of glass electrified with the silk, instead of the vulcanite. Result?

g. In the work of this experiment did the charge pass through the air from the electrified to the neutral body; *i.e.*, is air a conductor?

h. Charging a neutral body from one already electrified, without contact and without a conducting medium, is called charging by **induction.** Is the resulting charge like or unlike the exciting charge?

Experiment 85. Determination of the Kind of Electrification by Means of the Electroscope. (*For the Instructor.*)

Apparatus. — The glass and vulcanite rods; silk and flannel used in Exp. 82; a stick of sealing wax; a piece of dry hard wood; a gold leaf (or aluminum leaf) electroscope (see Appendix, p. 276).

Caution. — Observe the Note of Exp. 82. Never allow the electrified rods to come in contact with the ball of the electroscope, as the leaves are liable to be torn by too rapid movement. For the same reason, never bring an electrified rod suddenly near the ball.

Directions. — *a.* Bring, separately, the *neutral* rods of glass, vulcanite and sealing wax, as well as the pieces of silk and flannel, near the ball of the electroscope, and determine whether there is any movement of the leaves.

b. Electrify the glass rod by rubbing it with the silk, and slowly bring it near the ball of the electroscope. Result? Why? Remove the rod and note the result. Repeat.

c. Again bring the electrified glass rod near the ball, and while the leaves are divergent touch the ball with a finger. Result? Why? Remove, first the rod, then the finger.

d. Repeat *c*, and while the rod is near the ball, remove the finger and then withdraw the rod. Result?

e. If the rod was electrified positively in *b*, what kind of electrification was on the ball? On the leaves? Give reason for your conclusion.

f. In *c* when the ball was touched by the finger, why did the leaves collapse?

g. After withdrawing the finger and rod in *d*, why did the leaves diverge again?

h. Discharge the electroscope and repeat *b*, *c*, *d*, and *e* with the vulcanite rod, which has been rubbed with the flannel. Remember the kind of electrification on it.

i. Discharge the electroscope and recharge it with the glass rod as in *d*. Slowly bring the electrified vulcanite rod near the ball. Result? Why? Remove the rod. Result? Why?

j. Rub the piece of dry hard wood with the flannel, and bring it near the ball of the electroscope while the leaves are divergent. What is the kind of electrification on it?

k. Determine the kind of electrification on the silk and flannel after they have been rubbed with the glass and vulcanite respectively. The cloth, however, may lose its electrification so rapidly, that it is difficult to determine it unless the cloth is fastened to some insulating support. Fasten the piece of silk to one of the glass rods and electrify the silk by rubbing it with the other glass rod, keeping the silk well insulated all the time. Quickly bring the silk near the ball of the charged electroscope. Result? What kind of electrification on the silk? Repeat, using the flannel, fastened to the same glass rod, and rubbed with the vulcanite. Result? What kind of electrification on the flannel?

l. Determine the kind of electrification which can be produced on some other body near at hand.

Experiment 86. The Electrophorus. (*For the Instructor.*)

NOTE. — All the machines in practical use for showing the phenomena produced by static (frictional) electricity are of the induction or influence type. When static electricity is required in comparatively small quantities, it is readily supplied by the simplest of all inductive machines, the electrophorus.

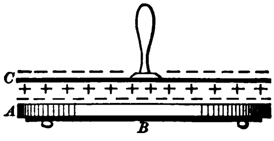

FIG. 51. — Electrophorus.

Apparatus. — An electrophorus, Fig. 51 (see Appendix, p. 277); a Leyden jar; a discharger; a catskin (or flannel).

Caution. — The insulating handle of the electrophorus must be thoroughly dry or failure is bound to result.

Directions. — *a.* Charge the vulcanite or wax plate *A* by rubbing it with the catskin. If now the metal disk *C* is placed on the charged vulcanite, the disk is charged by *induction*, positive electrification being found on its under side and negative repelled to the upper surface, as shown in the figure.

Lift the disk away by the insulating handle and test it with the electroscope for electrification. Result? Repeat.

b. Again bring the disk in contact with the charged vulcanite and touch the disk with the finger for a moment, thus connecting it with the earth. Remove the disk from the vulcanite and *slowly* bring it near the knob of the electroscope. Result? Test the disk for kind of electrification.

c. Remove the disk from the charged vulcanite after having touched it with the finger, and bring a knuckle near the edge. Result? Repeat.

d. Charge a Leyden jar by apparently passing several sparks from the disk into the knob. Discharge the jar with the aid of the discharger by touching the outer coating of the jar first with one knob, and then bringing the other knob slowly near the knob of the jar. Result? How does this spark compare in intensity with those obtained from the disk?

e. If the disk is charged by *induction* from the vulcanite, is any electrification removed from the vulcanite when the disk is lifted away? Why? If the room be dry, how many sparks can be drawn from the electrophorus after once charging the vulcanite?

f. How could a continuous acting electrophorus be devised?

ELECTRIC CURRENTS.

Experiment 87. Simple Voltaic Cell.

Apparatus. — An ordinary glass tumbler of about 400 cc. capacity; four pieces of No. 18 bare copper wire about 25 cm. long; dilute sulphuric acid (by volume 25 parts of water to 1 of acid); two blocks of pine wood about 10 × 2 × 3 cm.; two pieces each of sheet copper and sheet zinc about 10 cm. long by 3 cm. wide; four 10-oz. tacks; a small piece of sandpaper; a little mercury or amalgamating fluid (see Appendix, p. 278); two glass trays.

Preliminary Directions. — With a tack fasten one of the copper strips at the middle of one side of each block of wood, having first wrapped one end of a wire around the tack between the metal strip and the wood. In the same manner fasten the zinc strips on the opposite side of the blocks. Be careful that the tacks do not touch each other within the block. On the top of the block mark one pair of strips thus prepared *A*. Mark the other pair *B*. When the block rests on the top of the tumbler the lower ends of the metal strips should be about 5 mm. from the bottom.

Directions. — *a.* Sandpaper the zinc and copper strips till they are bright. Fill the tumbler about one-third full of the *dilute* sulphuric acid and place pair *B* of the metal strips in the tumbler. Keep the two metal strips apart so that neither they nor their connecting wires can touch each other at any point. Observe for about a minute the surfaces of the copper and zinc. Is any action noticed? If bubbles of gas arise from the surface of either metal, it is evidence of chemical action somewhere. Record your observations.

b. Never twist wires together unless for a permanent connection. For all temporary connections use double connectors. Allow the wires to come in contact with each other. What change, if any, is noticed?

c. Remove the strips from the liquid, wash them thoroughly, and then touch the ends of the two wires to your tongue at the same time. Note carefully the taste, if any, then immerse the strips in the acid as before, and while immersed, again touch the tongue with the ends of the two wires. Is the apparent taste of the wires affected in any way by thus immersing the strips in the acid? If so, why? Place the strips in the tray and rinse thoroughly both the strips and the tray.

d. Clean the surface of the zinc of the *A* strips if it is not already bright; wet it with the dilute acid and, while wet, rub a little mercury over the surface or, better, dip the strip in a tumbler of amalgamating fluid. *The copper must not be allowed to touch for an instant any mercury or amalgamating fluid;* neither should the zinc and copper strips touch each other after the zinc is amalgamated. Immerse as in *a* and look for evidence of chemical action on the surfaces while the two strips are entirely separated; also when the two wires are allowed to come in contact. Record your observations. Remove the strips from the acid, place them in the second tray, and rinse thoroughly. See that the *A* and *B* strips are in different trays.

Caution. — Do not leave the strips standing in the acid when not in use; remove, rinse, and place as directed, never on the table.

e. Examine a pair of plates which have been used for some time in a voltaic cell. Compare these plates with new ones. That plate of a cell which disappears the more rapidly is called the positive (+) plate; the other the negative (−) plate. Which plate is +? Which is −?

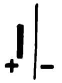

FIG. 52.

Fig. 52 shows the conventional method of indicating the plates or elements of a cell; the positive plate being represented by a short heavy line, while the negative plate is indicated by a longer fine line.

For convenience, the current is said to flow from the positive plate through the liquid of the cell to the negative plate, and then on through the connecting wire as indicated by the arrows in Fig. 53, thus completing the circuit. If there is such a current, it will evidently reach the point *A* (Fig. 53) before it reaches *B*; and it will reach *B* before it reaches *C*, etc. Therefore, since the current is always supposed to flow from a positive to a negative point, *A* would be positive and *B* negative with reference to each other, whereas *B* would be positive and *C* negative if these two points were referred to each other.

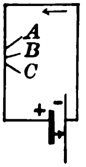

FIG. 53.

Suppose now that the connecting wire be cut between *B* and *C*, the end of the wire at *B* would be +, and that at *C* −, as shown in Fig. 54. The ends of such conductors through which a current might be passed are called **poles** or **electrodes.** To distinguish them from each other, the positive pole is called the **anode,** while the negative is called the **cathode.**

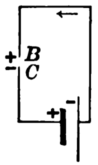

FIG. 54.

Note that the negative pole is attached to the positive plate of the cell, and *vice versa.*

f. Make a sectional drawing of a simple cell showing the direction in which the current flows.

NOTE 1. — If zinc is allowed to stand in dilute acid, it is acted upon chemically and soon disappears, being apparently dissolved by the acid. This, however, is prevented by rubbing mercury over its surface. This latter process is called amalgamation. This does not prevent the dissolution of the zinc when it is placed in metallic connection with the copper, as was done in *d.*

NOTE 2. — If but one person is to use the strips, one pair only will be required; however, if several are to perform the experiment, the two sets of strips are necessary as described.

Experiment 88. Work with the Voltaic Cell.

NOTE 1. — The peculiar phenomena observed in Exp. 87 become less apparent the longer the zinc and copper are left in metallic contact at the top. This "running down" of the cell is caused by the accumulation of gas on the copper plate. To overcome this difficulty and secure constant results, several forms of cells have been devised. One of these forms is to be used in this experiment. When zinc is used as one of the plates of a voltaic cell, it is almost always the positive plate. This is the case with the cells mentioned below.

NOTE 2. — For various reasons a "dry" cell is preferable for much of the work in electricity, unless a continuous current or a constant current is required. A dry cell, however, polarizes quite rapidly when in use (see Exp. 94), and where such a current is required would be unsatisfactory, unless there were considerable resistance in the circuit. As there is much resistance in the present experiment, a dry cell is entirely satisfactory if in good order. Although it is especially true of a dry cell, it is usually a good plan to have in a circuit **a spring contact key,** so that the current shall be automatically cut off except when actually in use, thus giving the cell a chance for a rest. One of the most satisfactory dry cells is the "Phœnix."

Apparatus. — A good voltaic cell (the "Globe Fuller" is a good one); two pieces of insulated copper wire about No. 18 and about

60 cm. long; two pieces of electric light carbon, *not coppered*, about 10 cm. long; a glass tumbler; a *saturated* solution of copper sulphate; a potassium iodide solution made by dissolving 1 part of the iodide in 4 or 5 parts of water.

Directions. — *a.* Fill the tumbler to a depth of about 1 cm. with the copper sulphate solution. Remove the insulating covering from about 2 cm. of one end of each of the copper wires. Scrape the ends bright and connect with the binding posts of the cell. Remove about 20 cm. of the covering from the other end of each wire and wrap this end of each wire closely around a carbon near its end, one wire on each carbon. There must be good contact of the metal with the carbon and with the part of the cell to which it is attached.

Set the carbon rods in the solution of copper sulphate, keeping them about 1 cm. apart. Do not allow the solution to wet the carbon where the wire is wrapped around it. The pair of carbons and wires must be entirely separated at all points.

Allow the carbons to remain in the solution a few minutes, then remove and examine the parts previously immersed. Notice carefully the appearance of any deposit on the rods. If satisfactory results are not obtained, place the rods closer together and repeat; if still unsatisfactory (this will be due to the weakness of the cell), connect the zinc of one cell with the copper (or carbon) of another and repeat the work, treating the combination as though it were a single cell. *Remove the rods from the solution as soon as any deposit is seen.* Notice whether the rod on which the deposit is found is connected with the zinc or the carbon of the cell, *i.e.*, whether it is the positive or negative electrode, the anode or the cathode (see Exp. 87, *e*). Then change the connection of the wires with the cell but not with the carbons, making the rod that was the cathode now the anode, and *vice versa*, immerse the carbons as before and describe any results noticed. Repeat until you have determined whether the carbon rod on which the deposit is formed is always the anode or the cathode, and whether the deposit will be removed if the rods be exchanged.

b. Remove the wires from the carbons, straighten and clean these ends of the wires, but keep the same connection of the wires and cell.

Moisten a piece of paper with the potassium iodide solution, lay it on the table and place the electrodes on the paper about 1 cm. apart. If a colored mark is not made on the paper by one of the wires, moisten the paper again with the solution and bring the electrodes closer together, even to within 1 mm. if necessary. Which electrode produced the change in color if any was noticed? Repeat several times. Change the cell connections of the wires and repeat. Compare these results with those obtained in *a*.

c. The work of this experiment illustrates the subject of **Electrolysis,** and this is the basis of all **electroplating,** actual copper-plating being the result in *a*. In such electroplating the *metal* is *always* deposited on the same electrode. Which one is it found to be? Is *iodine*, which produced the color in *b*, a metal or not?

Experiment 89. Effects Produced by Bringing a Wire Connected with a Voltaic Cell near a Magnet.

Apparatus. — A voltaic cell such as was used in Exp. 88; a delicately poised magnetic needle (see Fig. 55) about 5 cm. high, or a

pocket compass, or an ordinary sewing needle will answer, magnetized as in Exp. 71 and suspended by a silk fiber; a piece of pine wood about 30 × 1 × 1 cm.; a piece of No. 18 insulated copper wire about 1 m. long; another piece of the same wire about 2 m. long, with about 100 cm. of its middle portion wound into a flat coil of 4 or 5 turns so that the needle can be easily placed inside.

Directions. — *a.* Place the needle in such a position that no iron or steel shall be within a meter of it. Fasten with string or with two small staples, about 12 cm. of the middle part of the shorter wire to one end of the stick, as shown in Fig. 55. Connect the ends of the wire with the binding posts of the cell. Hold that portion of the wire which is fastened to the stick parallel to the *present position* of the needle and about 1 cm. directly above it, as in Fig. 55. Do not move the wire, even though the needle should move. What takes place? If the needle moves, give it time to come to rest, while the wire is held in its first position. Always keeping the wire in this position, disconnect one end of the wire from the cell. Result? Reconnect by simply touching the free end of the wire to that pole of the cell to which it was previously fastened. Thus "make" and "break" connections several times and notice whether the North-Seeking end of the needle is deflected toward the west or east. Record results in the table below.

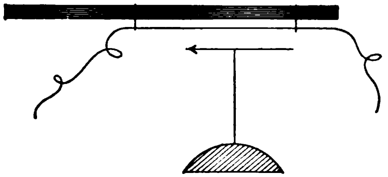

FIG. 55.

b. Repeat *a* with the wire below the needle.

c. Reverse the current; that is, if the current was flowing from north to south in *a* and *b*, turn the stick with its wire, end for end, so that the current shall now flow from south to north, and repeat *a*, noting once more whether the North-Seeking pole of the needle is deflected toward the west or east.

d. Repeat *c* with the wire below the needle.

Current Flowing from	Direction of Deflection of *N.-S.* End of Needle
N. to *S.* above	
N. to *S.* below	
S. to *N.* above	
S. to *N.* below	

e. Bend the wire in a loop so that one arm shall be above and the other below the needle and parallel to its position when at rest, as shown in Fig. 56. "Make" the cell connection. Compare the amount of deflection of the needle after it comes to rest with that obtained above.

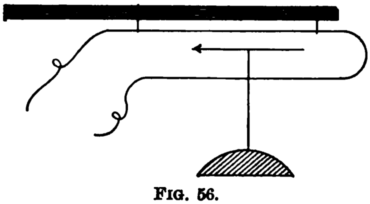

FIG. 56.

f. Remove this wire and in its place connect the coil of wire. Hold the coil in a vertical position, similar to that in which the loop in *e* was held, so that the needle shall be in the center of the coil with the current passing above and below the needle. Make and break connections as in *a* and notice the direction and magnitude of the deflection.

g. Reverse the current as in *c* and notice the direction of deflection. Is the amount of deflection greater than in *c*? Why?

h. From your observations, thinking of yourself as swimming in the "current of electricity" in the wire, in the same direction with it and always facing the magnetic needle, toward which side of you, the right or the left, will the North-Seeking end of the needle always be deflected? or

i. Place the palm of the *right* hand on the wire, palm toward the needle, the fingers pointing in the direction in which the current is flowing. Which end of the needle is deflected toward the thumb?

j. Derive a law by means of which the direction of a current in a wire can be determined, although nothing is known concerning the cell or battery.

Experiment 90. Some of the Effects Produced by Right and Left-Hand Helices with Soft Iron Cores.

NOTE. — In Exp. 74 it was noticed when either end of a piece of soft iron was brought near a magnetic needle that there was a movement on the part of the needle toward the iron. If the iron had been as free to move as the needle, mutual movement would have been noticed.

Apparatus. — A Globe Fuller, or other good cell; two pieces of soft iron about 10 cm. long and 1 cm. in diameter; a mounted magnetic needle as in Exp. 89; two pieces of No. 18 insulated copper wire, each about 2 m. long; a spring contact key; iron filings.

NOTE. — By means of the spring contact key the circuit may readily be closed or broken. Furthermore, the key will automatically break the circuit and thus prevent useless action in the cell.

Preliminary Directions. — Wind the wires, one on each of the two soft iron rods, so that beginning at the corresponding ends one wire will be wound on its **core** (the piece of soft iron) in the direction in which the hands of a clock move, and the other will be wound in the opposite direction. Wind the cores nearly full with one layer of wire, leaving about 25 cm. of wire free at each end for connection with the cell.

Directions. — *a.* Dip each end of the core of *A* (Fig. 57) successively in iron filings. Result?

b. Connect the ends of the wire to the binding posts of the cell through the contact key and repeat *a* with the circuit closed. Result? What has the core now become? Break the circuit and repeat *a*. Result?

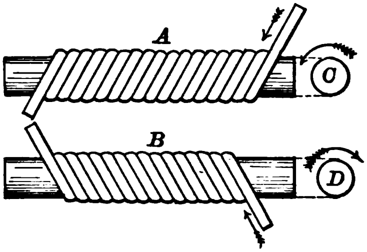

FIG. 57.

c. Hold the end of the coil at which the current enters, near the North-Seeking pole of the needle and close the circuit. Result? Repeat with the other end of the coil. Result? Change the connections and repeat.

d. Repeat *a*, *b*, and *c* with coil *B* and its core, noting and recording results as before.

e. Remove the iron core from the coil and repeat *c* with the coil alone. Result?

f. Sketch these helices correctly, naming the poles *C* and *D*, and showing the direction of the current.

g. If you imagine yourself swimming in and with the current of electricity and facing the soft iron core, on which side of yourself is found the North-Seeking pole of the magnet which the soft iron has now become?

h. Soft iron when magnetized as in this experiment is called an **electro-magnet.** The coil of wire is called a **right** or **left-hand helix,** depending on whether the wire is wound in the direction of the hands of a clock or oppositely. *A* of Fig. 57 represents a left-hand helix. Compare with the screw in Fig. 95.

i. From your observations state which pole is at the end where the current enters in the right-hand helix; left-hand helix.

j. Report to the instructor concerning *g* and *i* before taking up the next work.

The Tangent Galvanometer. Discussion.

One of the most important pieces of apparatus for use in electrical measurements is the **Tangent Galvanometer,** with which each pupil must become thoroughly familiar. (For the construction of this galvanometer see Appendix, p. 278.)

In setting up this instrument it should be placed, if possible, on a table or support which is free from all vibration. Level the galvanometer by means of the three leveling screws. The adjustment should be such that the plane of the coils will be in the magnetic meridian at the place where it is to be used. This can be accomplished by bringing the two ends of the *pointer* directly over the two zero points of the scale. Be careful not to confuse the magnetic *needle* with the *pointer*. The needle is always quite short, while the pointer is much longer and placed at right angles to the needle. When once adjusted *the instrument must not be disturbed during the process of an experiment;* in fact, if the instrument is to be used in several experiments it would be best not to disturb its adjustment until all have been performed. On this account flexible lamp cord wire is most satisfactory for making connections with the instrument. There should be no iron or steel within a meter of the galvanometer. If a movement of the needle is noticed as the pupil approaches, it is a sure sign that there is iron or steel, such as a knife, keys, stays, etc., about the person; these must be removed before satisfactory work can be accomplished.

In reading the instrument it may often happen that the two ends of the pointer do not indicate the same deflection. These errors may be caused by any one or more of four or five reasons. The center of the graduated circle may not be coincident with the center about which the needle turns, the pointer may be bent, or not placed at right angles to the axis of the needle, or the scale divisions may not all be equal each to each. In order to eliminate these errors of construction it is absolutely necessary to take the reading at each end of the pointer, and then reverse the current through the galvanometer by means of a **commutator** and take the two readings again. The average of these four readings must be taken as the true deflection. In taking the readings the pupil must be careful to avoid parallax (see Exp. 1, Note). This may be done by placing the eye so that the needle covers its image in the mirror (if a mirror is provided). Tap the glass cover of the galvanometer gently before each reading, to overcome friction of the needle. Unless the end of the pointer is very thin, select *one edge* to be read in all cases.

It was learned in Exp. 89 that if a current passed around a needle a greater number of times it produced a greater deflection of the needle. On that account it is customary to construct tangent galvanometers so that a greater or less number of turns of wire may be used as desired.

For accurate work the angles of deflection should not be very far removed one way or the other from 45°. If possible, keep the deflection between the angles of 30° and 60° (see Stewart & Gee, "Elementary Practical Physics," Vol. II, p. 230).

It is to be noted that if two currents which are passed through the tangent galvanometer, one after the other, deflect the needle, respectively, 36° and 54°, using the *same* number of turns of wire in each case, their relative strengths are *not* in the ratio of 36 to 54, but in the ratio of the tangent of 36° (tan 36°) to the tangent of 54° (see explanation of trigonometrical terms below). Or, if C and C' represent, respectively, the two currents, then

$$C : C' = \tan 36^\circ : \tan 54^\circ.$$

From the table of tangents, Appendix, p. 309, it is learned that the tangent of 36° is 0.727, and the tangent of 54° is 1.380.

$$\therefore C : C' = 0.727 : 1.380.$$

This then is the reason for calling this instrument a *tangent* galvanometer.

The above explains its use for determining *relative* current strength.

EXPLANATION OF THE TRIGONOMETRICAL TERMS, *Tangent* AND *Sine* OF AN ANGLE.

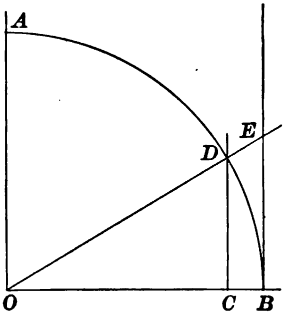

FIG. 58.

Let ADB (Fig. 58) be the quadrant of a circle whose center is O and radii OA and OB, and let DOB be any angle in the quadrant. Draw BE perpendicular to OB until it intersects OD produced in E. Draw DC perpendicular to OB.

Then the **tangent** of the angle BOD is the ratio of BE to OB or $\frac{BE}{OB}$. If OB has the value 1, *i.e.*, if the circle is constructed with a unit radius, [the line] BE will represent the tangent of the angle BOD.

The ratio of DC to OC, or $\frac{DC}{OC}$, is called the **sine** of the angle BOD.

The numerical value of the functions of the angles between 0° and 90° has been calculated. The value of the tangent and sine of every whole degree between 0° and 90° is given on p. 309 of the Appendix.

From the above discussion it will be seen that the tangent galvanometer can be used to determine the *absolute* strength of an electric current, provided the strength of some other current is known. For example, suppose that a current of 1.5 amperes when passing through a tangent galvanometer gives a deflection of 40°, and another whose strength is to be determined gives a deflection of 50°; then if x represents the unknown current, the following proportion is true:

$$1.5 : x = \tan 40° : \tan 50°$$

$$\text{or } 1.5 : x = 0.839 : 1.190,$$

as found in the table, Appendix, p. 309. Therefore $x = 2.12$ amperes, the strength of the unknown current.

In using a tangent galvanometer for absolute measurements, take for the known current that current which will give a deflection of 45°, simply because the tangent of 45° is 1.00. This current then can be called the **reduction factor** of the galvanometer (see Exp. 105). For instance, if a current of 1.2 amperes is required to produce a deflection of 45°, and an unknown current is found to produce a deflection of 40°, then

$$1.2 : x = 1 : 0.839.$$

$$\therefore x = 1.0068 \text{ amperes.}$$

Each coil of the galvanometer has its own reduction factor, which must be determined before the instrument can be used for the determination of current strengths.

Experiment 91. How Does Changing the Length or Size of a Conductor Affect the Strength of the Current?

Apparatus. — A tangent galvanometer (or a galvanoscope with a graduated scale); a constant voltaic cell; a set of resistance spools (see Appendix, p. 280); a commutator (for changing the direction of the current); six pieces of insulated copper wire No. 18, about 50 cm. long, for connections; a spring contact key.

Directions. — *a.* Place the galvanometer and resistance spools near the center of the table, setting the galvanometer as directed in the Discussion, p. 186. When once set in place, it must not be disturbed in the slightest during the process of the experiment. Connect the different pieces of apparatus as shown in Fig. 59, passing the current through spool No. 1. Record in the table below the direction and amount of deflection in degrees of each end of the needle. By means of the commutator reverse the current through the galvanometer and record the amount of deflection as before.

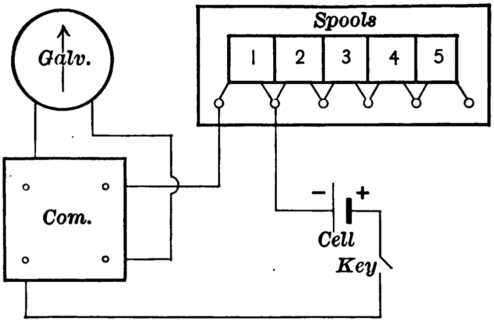

FIG. 59.

b. Now introduce the remaining spools and the combination as indicated in the table, recording the deflection each time as indicated.

Trial	Spool	DEFLECTION					Relative Current Strength or Tangent of Angle of Deflection
		NORTH END		SOUTH END		Mean	
		East	West	East	West		
1	1						
2	2						
3	3						
4	4						
5	1, 2, 3 & 4						

c. How does introducing either a longer or a finer wire affect the amount of deflection of the galvanometer needle? Does a longer wire appear to use up more of the current? Is the same true of a finer wire? This apparent hindrance to the electric current is called **resistance.**

d. Does increasing the resistance increase or decrease the strength of the current flowing through the wire? Give reason for your conclusion.

Experiment 92. To Increase the Sensitiveness of the Tangent Galvanometer.

Apparatus. — A tangent galvanometer; a resistance box; a commutator; a cell; a bar magnet about 15 cm. long; six pieces of wire for connections; a contact key.

NOTE. — The unit of electrical resistance is called the **ohm** and is the resistance of a uniform column of mercury 106.3 cm. long and 1 sq. mm. in area (14.4521 g. in mass) at 0° C.

Directions. — *a.* Connect the apparatus as shown in Fig. 60, setting and using the galvanometer as directed in the Discussion, p. 186. Close the circuit through the galvanometer with 1 ohm resistance in the box and record the deflection of the two ends of the pointer. How much

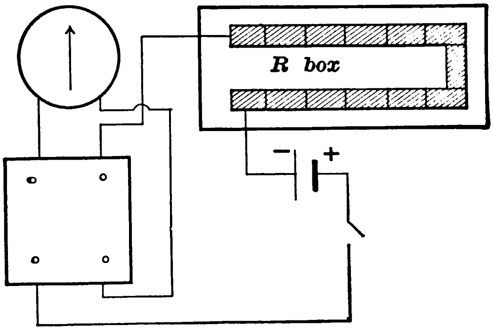

FIG. 60.

difference does it make whether the plugs are twisted firmly into place; *i.e.*, is it necessary that the contact be good? Try it. Now by means of the commutator reverse the current through the galvanometer and again record the readings of the two ends of the pointer. Introduce the resistances indicated in the following table and determine the corresponding deflections, continuing the work by adding 10 ohms in each trial till the deflection becomes less than 5°. Note that the resistance of the balance of the circuit is to be added to that in the box in each case.

RESISTANCE OF GALV. .... OF CELL .... COM. AND WIRES ....
TOTAL RESISTANCE OUTSIDE THE BOX .... OHMS.

Trial	Ohms resistance			DEFLECTION					Relative Current Strength, or Tangent of Angle of Deflection
				NORTH END		SOUTH END		Mean Deflection	
	In Box	Outside the Box	Total	West	East	West	East		
1	1								
2	2								
3	4								
4	6								
5	8								
6	10								
7	20								
8	etc.								

b. How does introducing more resistance influence the deflection?

c. How do the current strengths (tangents of deflections) compare in Trials 3 and 4? 3 and 7? 6 and 10? 9 and 12? 8 and 12?

d. Place the bar magnet on the table with its North-Seeking pole about 25 cm. from the South-Seeking pole of the galvanometer needle (unlike poles toward each other), and in the plane of the galvanometer coils, so that the pointer is at 0° when no current is passing through the instrument.

Throw into the circuit the resistances given in the following table and record the deflections. Unless the end of the pointer is very thin, select one edge to be used *in all cases.*

North-Seeking Pole of Magnet toward South-Seeking Pole of Galvanometer. (Unlike Poles toward Each Other.)

Trial	Ohms	About 25 cm. Apart					About 40 cm. Apart				
		North End		South End		Mean	North End		South End		Mean
		West	East	West	East		West	East	West	East	
1	1										
2	4										
3	10										

e. Repeat *d* with the magnet about 40 cm. from the needle, recording results in the above table.

f. Turn the magnet end for end (like poles toward each other) and repeat *d.* Record results in a table similar to the last.

g. Repeat *f* with a distance of about 40 cm.

h. In which one of the two tests, *d* or *f*, does the needle vibrate for a longer time? In which of these two tests would a weak current be indicated the more readily? *i. e.*, which is the more sensitive test, with like or unlike poles toward each other? How, then, could a magnet be used to make a tangent galvanometer more sensitive?

Experiment 93. An Electromotive Series.

Apparatus. — The tumbler and acid of Exp. 87; a tangent galvanometer; strips of carbon, copper, iron, lead, and zinc, each about 10 × 2 cm.; a porcelain or glass dish; two pieces of wire for connections, or better, a piece of double flexible lamp cord.

NOTE. — Always keep the wet strips in the porcelain dish when not in use. Use all the galvanometer coils.

Directions. — *a.* Attach the wires to the galvanometer. Hold the free end of one wire in contact with the copper strip; the free end of the other wire in contact with the zinc strip, thus forming the elements of a cell. Holding these two strips in the hands, place them in the acid and note the direction in which the needle is deflected. At which binding post does the current enter the galvanometer? If the current should enter at the other post, would the needle be deflected in the same direction? Which plate is positive and which negative? Record as Trial 1 in the table.

Trial	Positive Plate	Negative Plate
1	Zinc	Copper
2		
3		
4		
5		
6		
7		
8		
9		
10		

b. Repeat *a*, using the carbon strip in place of the copper. Which of these is found to be the positive and which the negative plate? Record as Trial 2. Proceed in this manner until all possible pairs of the five plates have been tried.

c. Arrange the substances in such order, in the table

	Series
1	
2	
3	
4	
5	

headed "Series," that if any two of them were selected for the elements of a cell the one occurring first in the series would be the *positive plate.*

d. Repeat the work with the same strips, but using a sodium bichromate solution in place of the acid.

Experiment 94. To Determine the Rate of Polarization of Voltaic Cells.

Apparatus. — A tangent galvanometer; the simple cell of Exp. 87, a Leclanche porous cup cell, a dry cell, or any other open circuit cell which polarizes readily; a Daniell or other *constant* cell (see Appendix, p. 281); a resistance box.

Directions. — *a.* Connect the simple cell, resistance box, and galvanometer in circuit, adjusting the resistance in the box until the galvanometer reading is between 45° and 50°. It is best to use as little resistance as possible but to vary the number of coils of the galvanometer to produce the desired result. As soon as the needle comes to rest, record the reading without reversing. Keeping the circuit closed, record the reading of the needle at intervals of 1 minute for 15 minutes, or until the deflection has decreased to about 10°. **Be careful not to disturb the cell in any way,** but tap the glass cover of the galvanometer gently before each reading.

b. Now shake the negative plate, observing the needle closely. Result? Why?

c. Repeat *a* with the Daniell cell. Why the difference in results?

d. Record results in the following table:

Time	SIMPLE CELL		DANIELL CELL	
	Degrees of Deflection	Tangent of Deflection	Degrees of Deflection	Tangent of Deflection
9-27				
etc.				

e. Plot the results in the form of curves, making the times abscissas and the tangents ordinates, using any convenient scale. Plot both curves from the same origin.

f. The results noticed in connection with the simple cell are due to polarization. **Polarization** is caused by the accumulation of a gas (hydrogen) on the negative plate.

NOTE. — The greater the resistance in any circuit, the smaller the current will be; therefore there will be less polarization and the cell will be more nearly constant.

Experiment 95. Effect, on the Current Strength, of Varying the Battery Resistance.[1]

Apparatus. — Two Daniell cells (see Appendix, p. 281); a tangent galvanometer; a commutator; a resistance box; two double connectors; wires for connections.

Directions. — *a. Variation of Effective Plate Area.* Fill the porous cups with dilute acid to the usual level. Let the cups stand outside the glass jars till a film of moisture gathers on the outside, showing that the liquid has filled the pores. Otherwise the current may increase for a few minutes, owing to the gradual driving out of the air contained in the pores of the cups. Then finish putting together the cells in the usual way.

---

[1] This experiment is adapted from the Harvard pamphlet.

b. Connect one of the cells in circuit, through the commutator, with the galvanometer, using such coils as shall give a deflection of about 60°. Keeping the copper and zinc as near together as possible (see Fig. 61), record the reading. Then reverse the current and record again.

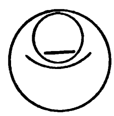

FIG. 61.

c. Without changing the distance between the copper and zinc, raise both of them till they dip about 1 cm. only below the surface of the liquids. While they are in this position read, reverse and read again.

d. Variation of Distance between Plates. Keeping the porous cup in contact with the side of the jar, put the plates as far apart as possible (see Fig. 62), and while they are in this position read, reverse and read again.

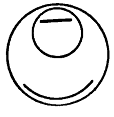

FIG. 62.

e. What is the effect upon the strength of the current of varying: 1) the *effective area* of the plates; 2) the *distance between the plates?*

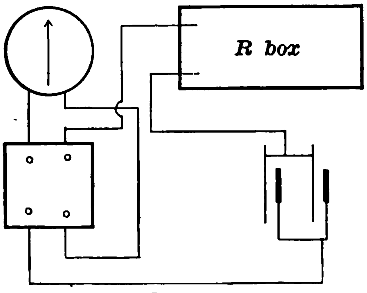

FIG. 63.

f. Cells in Parallel. Join the two cells in **parallel**, zinc to zinc, and copper to copper, and put them thus joined in circuit with the galvanometer, commutator, and the resistance box (see

Fig. 63). Adjust the resistance in the box, so that about 0.1 ohm shall be in the circuit; read, reverse and read as before. Now introduce a resistance of about 10 ohms, read and record as before.

g. Cells in Series. Join the two cells in **series,** zinc of one cell to copper of the other, the other connections being as before (see Fig. 64). Take readings with identically the same resistances as in *f.* These readings must be with the same galvanometer coils that were used in *f.*

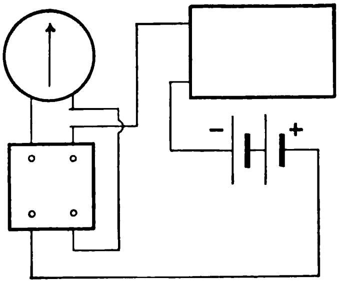

FIG. 64.

h. Under what conditions do cells connected in **multiple** (or parallel) give a stronger current than cells connected in series? Under what conditions do cells, in series, give the stronger current?

Experiment 96. Measurement of Resistance with the Tangent Galvanometer — by Substitution.

Apparatus. — Any *constant* voltaic cell; a resistance box; a tangent galvanometer; set of unknown resistances of Exp. 91; wires for connections; a commutator; a spring contact key.

Directions. — *a.* Connect spool No. 1 in circuit, as in Fig. 65. Read by reversals, and take the mean of these readings as the deflection to be used.

b. Now substitute the resistance box for the spool of wire and adjust the resistance in the box until the deflection is the same as for the spool. Read by reversals as in *a*. The total resistance introduced in the box will be the resistance of the spool. Why?

c. Proceed in the same way with each of the spools and record results in the following table. The diameter of the wires should be known accurately. Use a micrometer caliper for this.

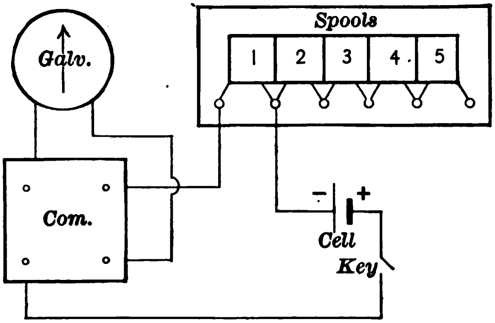

FIG. 65.

Spool	No. of Wire (B. & S.)	Diameter	Length	Kind	Deflection	Resistance
1	22	...... mm.	10 m.	Copper		
2	28		10	Copper		
3	22		20	Copper		
4	28		20	Copper		
5	28		10	German Silver		

d. What relation can be seen between the lengths of conductors of the same diameter and their resistances?

e. What relation between the diameters and resistances, the lengths being the same?

f. How does the resistance of German silver compare with that of copper?

NOTE. — It is to be borne in mind that German-silver wire contains no silver. It is composed of five parts copper, two of nickel, and two of zinc.

Experiment 97. The Wheatstone Bridge.

References. — Kempe's "Handbook of Electrical Testing," p. 188; Atkinson's "Dynamic Electricity," p. 157; Carhart & Chute, p. 232; Ayrton's "Practical Electricity," p. 241; Avery's "School Physics," p. 532.

Preliminary Apparatus. — A voltaic cell; a D'Arsonval galvanometer with two wires a meter or so in length connected with it; an iron wire, No. 27 or finer, and a meter (or more) in length; spring contact key. (Almost any galvanometer will answer.)

Preliminary Directions. — *a.* Connect the cell, key, and iron wire in circuit. When the circuit is closed a current passes. The current is said to flow from a point of high potential to one of low potential. It follows then that if two points are at the same potential, no current will pass between them.

b. Bring the free ends of the galvanometer wires in contact with the iron wire (through which a current is passing) at the same point. Is any current noticeable through the instrument?

c. Keeping the two wires continually in contact with the iron wire, slowly separate them from each other. They are now at points of different potential on the iron wire. What is the result on the galvanometer? Why? Is part of the current still passing through the iron wire? (If in doubt cut the wire and note the effect on the galvanometer.) Is part of the current passing through the galvanometer? Such a *divided circuit* is called a **shunt.**

Part of the current is said to be **shunted** through the galvanometer. Either part of the divided circuit is considered as a shunt to the other part.

Discussion. — The Wheatstone Bridge is an instrument for measuring an unknown resistance by comparison with a known resistance. The theoretical arrangement of the bridge is shown in Fig. 66. It consists of four resistances, a, b, d, and x, (arranged in the form of a parallelogram); a battery occupying the place of one diagonal, a galvanometer the other. When the resistances are so arranged that no current flows through the galvanometer (when the points C and D have the same potential), these four resistances have a definite relation to each other. This relation can be determined in the following manner:

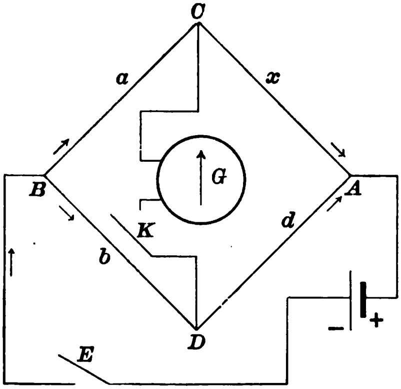

FIG. 66.

By Ohm's Law $E = CR$; *i.e.*, at any point in a circuit the electromotive force, or potential, is equal to the product of the current times the resistance.

Now the current at B divides into two parts, BCA and BDA. Represent the current passing through BCA by C'; that through BDA by C''. Then the E. M. F. at C will equal $C'a$ (current times resistance); that at D, $C''b$.

If $C'a > C''b$, a current will flow through the galvanometer from C to D. If $C'a < C''b$, a current will flow from D to C. But if $C'a = C''b$, then C and D have the same E.M.F., and no current will flow through the galvanometer. But also $C'x$ must equal $C''d$, otherwise there will be a current from C to D, or D to C, as the case may be.

Since to have C and D at the same potential,

1) $C'a = C''b$, and

2) $C'x = C''d$, dividing 1) by 2) gives

3) $\frac{a}{x} = \frac{b}{d}$, or

4) $a : x = b : d$, from which $bx = ad$, or

5) $x = \frac{ad}{b}$.

In some forms of the Wheatstone Bridge two of the resistances are fixed, and the third is adjustable, the fourth being the resistance whose value is to be found. Ordinarily a and b should be made the fixed resistances, d the adjustable resistance, and x the unknown resistance.

In the use of the bridge three methods of arranging the resistances in the arms suggest themselves.

First Method.

a and b may be made of equal value, in which case d is adjusted until equilibrium is produced, when $x = d$. This method is used below in this experiment. (See Fig. 68.)

There are some objections to this method. The resistance box may not have sufficient range, the ordinary style of box not containing coils of less value than one-tenth of an ohm. Or it may be desired to measure a greater resistance than the total resistance of the box.

Second Method.

The resistance *b* may be several times as large as *a*, usually 10, 100, or 1000 times as large, when $x = \frac{d}{10}, \frac{d}{100}$, or $\frac{d}{1000}$, as the case may be. If the resistance to be measured is greater than the total resistance of the box, *a* should be made 10, 100, or 1000 times as large as *b*; then the unknown resistance can be easily found. In this case $x = 10\,d$, $100\,d$, or $1000\,d$.

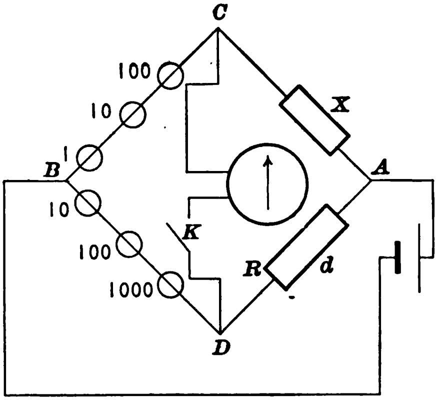

FIG. 67.

Combinations of Wheatstone Bridge and resistance box are made in which the proportional arms *a* and *b* can be thus adjusted, as in Fig. 67.

Third Method.

By means of a device called the "Slide Wire Bridge," *a* and *b* can be easily and accurately adjusted (see Exp. 98).

The following experiment illustrates the first of the above methods:

Apparatus. — A resistance box; a D'Arsonval galvanometer (see Appendix, p. 281) (or an astatic galvanometer); a voltaic cell; two double wire connectors; several pieces of insulated copper wire for connections; a fine German-silver wire No. 30 or 32, about 1 m. long, doubled on itself at the middle and twisted at this point for about 1 cm. It is preferable to mount the German-silver wire on a board provided with three binding posts, *C*, *B*, *D* (Fig. 68); the unknown resistances of Exp. 91 (or other resistance); two spring contact keys for closing the circuit.

NOTE. — If an astatic galvanometer is used, it must be adjusted until the pointer is at the zero of the scale before using.

References for the D'Arsonval galvanometer. — Kempe, p. 61; Carhart & Chute, p. 229; Avery's "School Physics," p. 527.

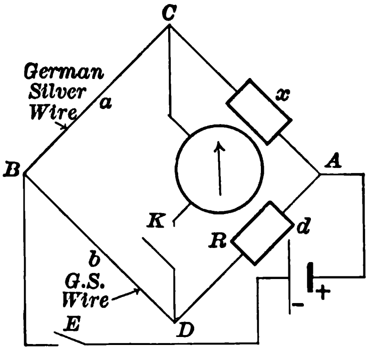

FIG. 68.

Directions. — *d.* Connect the apparatus as shown in Fig. 68, using the double connectors at *A* and *B*. The contact keys are at *K* and *E*.

Caution. — Always close the battery key *E* before closing the galvanometer key *K*. Always open *K* before *E*. If the battery key be opened or closed while the galvanometer key is closed, there will be a movement of the galvanometer needle, owing to self-induction. The key *K* should remain closed for an instant only, as the direction, not the amount, of deflection is to be observed.

e. Close first the battery key *E* and then the galvanometer key *K for an instant only*, and note the direction in which the mirror or needle of the galvanometer swings. Open first *K* and then *E*. Remove plugs of the resistance box. Make and break the circuit as before, noting the direction of the deflection. Proceed in this manner until the mirror or needle swings in the opposite direction. Adjust the resistance in the box until no movement of the mirror is noticed when K is closed. Then the resistance x equals the resistance of the box d (assuming that a and b are equal).

f. If there is time, repeat, using other spools, or any other unknown resistance.

g. Compare results with those of Exp. 96.

Experiment 98. The Slide Wire Bridge.

References. — Stewart & Gee, Vol. II., p. 149; Atkinson, p. 159; Kempe, p. 213. For construction of the slide wire bridge see Avery, p. 540; Hall & Bergen, p. 580, No. 106; Stewart & Gee, Vol. II., p. 107.

Apparatus. — A slide wire bridge; a D'Arsonval (or astatic) galvanometer; a voltaic cell; a resistance box; the unknown resistances of Exp. 91 (or other resistance); several wires for connections; a spring contact key.

Discussion. — This experiment illustrates the third method of Exp. 97, Discussion.

Since resistance is proportional to the length of a conductor, the proportion $a : x = b : d$, or $a : b = x : d$ (see Exp. 97, 4), becomes length of a : length of $b = x : d$. Therefore $x = \frac{(\text{length of } a)d}{(\text{length of } b)}$.

Directions. — *a.* Connect the apparatus as shown in Fig. 69, which represents the Chicago style of the slide wire bridge, or as in Fig. 70, which represents the ordinary form. Use in the box d about as much resistance as is supposed to be in x.

b. With the slide about 10 cm. from one end of the wire, close first the battery and then the galvanometer circuit *for an instant only.* Note the direction of the deflection. Now move the slide to about 10 cm. from the other end of the wire and repeat. If the deflection is in the same direction as before, adjust the resistance in the box until a change in the direction of deflection at those two points is obtained.

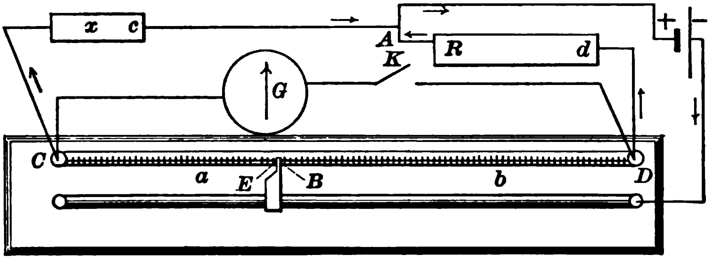

FIG. 69.

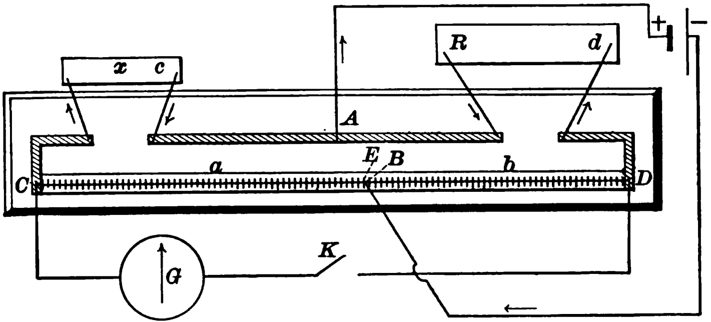

FIG. 70.

c. Move the slide towards the middle of the wire by successive steps, closing and opening the circuits at each step, until a place is found where no movement of the galvanometer needle is noticed. When this is found a movement of the slide about 1 mm. to either side should cause a slight deflection in opposite directions. If the resistance x is large, more accurate results may be obtained by *now* adding more cells to the battery.

d. Calculate the value of x in the equation

$$x = \frac{(\text{length of } a \text{ in mm.})\,d}{\text{length of } b \text{ in mm.}}.$$

e. Repeat with the other coils and compare with the results obtained in previous work.

NOTE. — As a check on the work thus done let x and d exchange places and repeat the work, taking the mean of the two results. This will tend to eliminate any errors caused by irregularity in the resistance of the slide wire. With this method the slide should be near the middle of the wire, making a and b nearly equal. This requires x and d to be nearly equal also. When the slide is near one end of the wire, the result will not be so accurate, for a mistake of 1 mm. in the position of the slide when it is near the end of the wire makes a greater error in the value of x than when it is near the middle of the wire. The greater the difference between a and b, the greater the error, as can readily be seen.

f. To measure the resistance of a galvanometer, introduce this galvanometer into the circuit at x, and treating it as an unknown resistance, *not* as a galvanometer, proceed as in *a*, *b*, *c*, and *d*. A second galvanometer will be required to be used at G as usual.

Experiment 99. Measurement of the Resistance of a Constant Voltaic Cell with a Tangent Galvanometer — by the Half-Deflection Method.

References. — Kempe, p. 113; Stewart & Gee, Vol. II., p. 229.

Apparatus. — Any *constant* cell; a tangent galvanometer whose

resistance is known; a commutator; a resistance box; wires for connections whose resistance is known.

Directions. — *a.* Connect as in Fig. 71, adjusting the resistance in the box and using such coils of the galvanometer that the deflection is about 55°. (The larger the resistance, the more constant the cell will be.) Read by reversals and take the mean of the four readings as the *angle of deflection*. Note exactly the number of ohms resistance in the box.

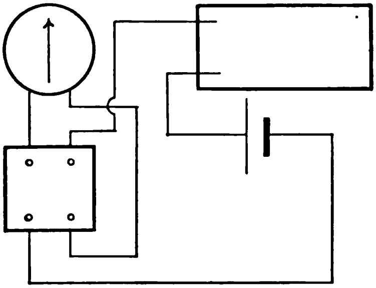

FIG. 71.

b. Consult the table of tangents (see Appendix, p. 309) and find the tangent of this angle of deflection. Take one-half of this tangent and find from the table the angle corresponding to it.

c. Now adjust the resistance in the box until the deflection of the needle (obtaining the mean as before) is equal to this new angle. It is evident that the present strength of current is just one-half the strength in *a.*

d. Notice how many ohms *additional* resistance were introduced in the circuit in order to reduce the strength of the current one-half. Since, from Ohm's Law, the strengths of the current are to each other inversely as the total resistances in the circuit, the additional resistance introduced must be equal to one-half the total resistance now in the entire circuit. Therefore this additional resistance must equal the total resistance at first.

e. Repeat *a* in order to see if the cell is constant.

f. The resistance of the galvanometer, connecting wires, etc., being known, the cell is the only unknown resistance, and this may now be readily calculated.

For example: The galvanometer resistance with the connecting wires is, say, 0.4 ohm. Suppose the cell, galvanometer, and 1 ohm of the box in circuit as in *a* give a deflection of 55°. The tangent of 55° is 1.430. Half this tangent is 0.715, which is found from the table to be the tangent of 35.5°. The *additional* resistance introduced to bring the deflection to 35.5° (to make the current strength one-half its first value) is, say, 7 ohms. This added resistance then must equal the total resistance in *a*. Then $7 = 1 + x + 0.4$, and $x = 5.6$ ohms, the resistance of the cell. In this manner determine the resistance of the cell used.

NOTE. — By reference to Stewart & Gee as above, it will be seen that the method here given is not strictly accurate. It is, however, a very close approximation.

Experiment 100. To Measure the Resistance of a Voltaic Cell — by Mance's Method with the Slide Wire Bridge.

Reference. — Kempe, p. 127.

Apparatus. — The slide wire bridge; a resistance box; a *sensitive* galvanometer (D'Arsonval, or astatic); a voltaic cell whose resistance is to be measured; wires for connections.

Directions. — *a.* Connect the apparatus as in Fig. 72. No contact keys are required. In the resistance box *d* introduce 1 or 2 ohms resistance. Call the resulting deflection the "permanent deflection."

b. Move the slide along the wire, depressing it at intervals, until a point is reached where the depression of the slide makes no change in the permanent deflection of the mirror. When this point is reached, the internal resistance of the battery can be calculated from the equation

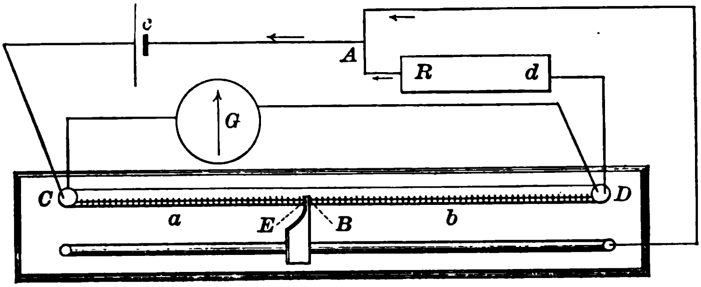

FIG. 72.

$$x = \frac{(\text{length of } a \text{ in mm.})\, d}{\text{length of } b \text{ in mm.}}.$$

NOTE. — If a cell is used which polarizes readily, the deflection of the mirror will gradually grow less. This will not affect the result, as the direction of the deflection is the important matter, not the amount of deflection. To insure good results, a reading telescope with scale should be used with a mirror galvanometer, D'Arsonval preferred.

As the internal resistance of a cell is not constant, but varies with use, the result obtained above is only correct for this particular experiment. Tests for battery resistance are very unsatisfactory.

Experiment 101. To Measure Battery Resistance by Use of an Ammeter and Voltmeter.

Reference. — Ayrton, pp. 366 and 492.

Apparatus. — A cell or battery to be tested; a delicate ammeter; a voltmeter; wires for connections; a resistance box.

Directions. — *a.* Connect the voltmeter to the cell and record the reading. Call this reading E.

b. Adjust the box so that there shall be a large resistance in it, then connect the ammeter, voltmeter, cell, and resistance box as in Fig. 73, where A represents the ammeter and V the voltmeter. Adjust the resistance in the box so that the current strength can be read on the ammeter. Read both the ammeter and voltmeter. It is customary to designate the resistance of a battery (or other generator) by r, and that of any or all other resistances in the circuit by R. Call the ammeter reading C, the corresponding voltmeter reading (difference of potential) E', the battery resistance r. Then from Ohm's Law,

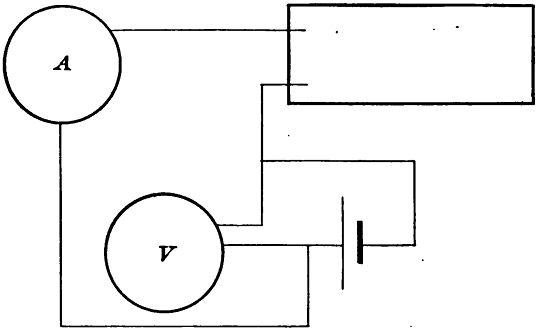

FIG. 73.

$$r = \frac{E - E'}{C} \text{ ohms.}$$

Experiment 102. Effect of Change of Temperature upon Resistance.[1]

Apparatus. — Any *constant* cell; a Wheatstone bridge; a D'Arsonval (or astatic) galvanometer; a thermometer; a temperature coil (see Appendix, p. 282); a resistance box; a vessel of ice water; the boiler of Exp. 58, without top, with boiling water.

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[1] Modified from Exp. 57, Harvard pamphlet.

Directions. — *a.* Connect the apparatus as in Fig. 74, with about one ohm of resistance in the box. Place the temperature coil in the vessel of ice water and connect the coil at *x*.

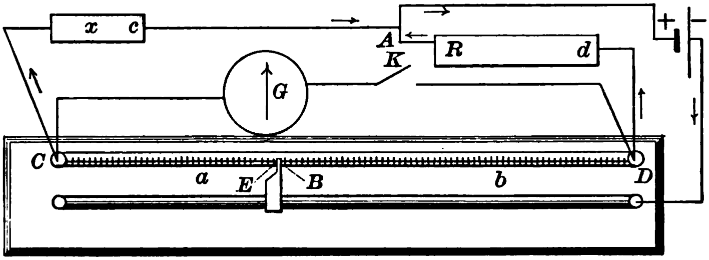

FIG. 74.

b. Measure carefully the resistance of the coil while it is in the ice water. Note the temperature of the coil, which is the same as that of the water.

c. Repeat *b* with the coil in the boiling water.

d. Repeat with water at other temperatures.

e. Plot a curve showing the relation between temperature and resistance, using temperatures as ordinates.

f. What is the effect of increase of temperature on electrical resistance?

Experiment 103. To Measure the Electromotive Force of a Cell by Wheatstone's Method.

References. — Stewart & Gee, Vol. II., p. 239; Kempe, p. 152.

Apparatus. — A Daniell cell; a voltaic cell whose E. M. F. is to be measured; a tangent galvanometer; a commutator; wires for connections; resistance box.

Directions. — *a.* Connect the apparatus as in Fig. 75, using the Daniell cell. Adjust the resistance in the box until the galvanometer reading is about 55°. If one cell does not give sufficient current use two or even three cells in series, and reduce the result accordingly. Now introduce additional resistance in the box until the reading is reduced to about 35°. Read by reversals. Call this *additional* resistance *R.*

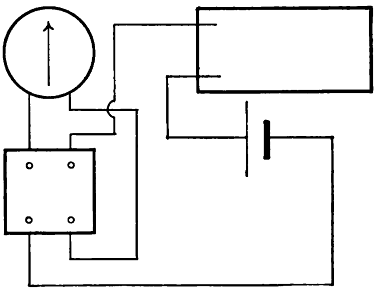

FIG. 75.

b. Remove the Daniell cell and substitute in its place the cell whose E. M. F. is to be measured. Adjust the resistance in the box as in *a*, until the same deflection is obtained as at first. Then adjust as in *a*, until the second deflection of about 35° is again obtained. Call this additional resistance R'.

c. The E. M. F. of a Daniell cell freshly set up is 1.08 volts (see Carhart's "Primary Batteries," p. 31). Call this E. Call the E. M. F. of the cell to be determined E'. Calculate the E. M. F. of the cell E' from the proportion $E : E' = R : R'$.

NOTE. — By this method it is not necessary to know the battery resistance, as the electromotive forces are directly proportional to the *added* resistances which in both cases were required to bring the deflections of the galvanometer needle from the first reading of about 55° to the second of about 35°.

Experiment 104. To Calibrate a Tangent Galvanometer.

Preliminary. — Galvanometer deflections vary according to strength of current, also according to resistance. A galvanometer is calibrated *relatively* when the relation between various strengths of current and the resulting deflections is known; or when the relation between various resistances and the resulting deflections is known. When the current strength is known in amperes, the galvanometer is said to be calibrated *absolutely*. There are many ways of doing this work. The following methods are among the simplest.

I. TO CALIBRATE RELATIVELY. (See Ayrton, p. 287.)

Apparatus. — A tangent galvanometer; a constant cell of *low* internal resistance, Edison-Lalande preferred; a commutator; a resistance box; wires for connections.

Directions. — *a.* Connect the apparatus as in Fig. 76. Introduce such a resistance in the box that the deflection will be about 10°. Make all deflection readings by reversals, as heretofore instructed. Call this resistance R_1, the galvanometer resistance g, and the deflection d_1.

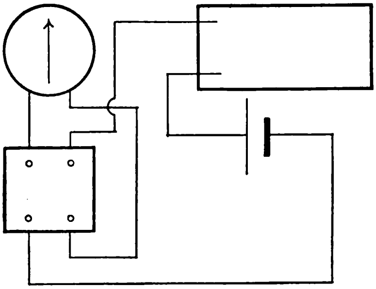

FIG. 76.

b. Now change the resistance to R_2, such that $R_2 + g = \frac{1}{2}(R_1 + g)$, or $R_2 = \frac{1}{2}R_1 - \frac{1}{2}g$. Then the current will be doubled, since from Ohm's Law the current passing through any circuit is inversely proportional to the resistance, *if a constant difference of potential is maintained at the ends of the circuit.* Call this second deflection d_2.

c. Next use a resistance R_3, such that $R_3 + g = \frac{1}{3}(R_1 + g)$, or $R_3 = \frac{1}{3}R_1 - \frac{2}{3}g$. Then the current will be three times as strong.

In like manner make about ten trials, using the formulæ $R_4 = \frac{1}{4}R_1 - \frac{3}{4}g$, $R_5 = \frac{1}{5}R_1 - \frac{4}{5}g$, etc.

d. Record results in the accompanying table and plot a curve, making the tangents of the deflections the abscissas, and the resistances the ordinates. State your conclusion from the results obtained.

Resistance	Deflection	Current Strength (Tan. of Deflection)
R_1	d_1	1 ....
R_2	d_2	2 ....
R_3	d_3	3 ....
etc.		

II. To Calibrate Absolutely. (See Ayrton, p. 521.)

Apparatus. — As in I, except that *any* cell of constant E. M. F. may be used.

Directions. — *a.* Determine the E. M. F. and internal resistance of the cell used. Call them E and r, respectively. Include in r the resistance of the connecting wires.

b. Proceed as in I, using the formulæ $R_2 = \frac{1}{2}R_1 - \frac{1}{2}(g + r)$, $R_3 = \frac{1}{3}R_1 - \frac{2}{3}(g + r)$, $R_4 = \frac{1}{4}R_1 - \frac{3}{4}(g + r)$, etc.

Calculate the current strengths in amperes from the formulæ

$$C = \frac{E}{r + g + R_1}, \qquad C_1 = \frac{E}{r + g + R_2}, \text{ etc.}$$

c. Record results in the accompanying form and plot a curve as before, using the amperes as ordinates and the tangents of the deflections as abscissas.

Resistance	Deflection	Amperes
R_1	d_1	C_1 ....
R_2	d_2	C_2 ....
R_3	d_3	C_3 ....
etc.		

Experiment 105. To Determine the Reduction Factor of a Tangent Galvanometer when the E. M. F. and R. of the Cell are known. (An approximate method.)

NOTE 1.—A more accurate method for the determination of the Reduction Factor is given in the next experiment.

Discussion.—The **Reduction Factor** of a tangent galvanometer is that quantity which, being multiplied by the tangent of the angle of deflection, will give the strength of the current in amperes. If K represents this factor and a the angle of deflection, then

$$1) \quad C = K \tan a \text{ or}$$

2) $K = \frac{C}{\tan a}$, but by Ohm's Law

3) $C = \frac{E}{g + R + r}$, where g is the resistance of the galvanometer, R and r being, respectively, the external and internal resistances of the circuit.

Substituting this value of C in (2)

4) $K = \frac{E}{(g + R + r)\tan a}$.

From (4) K can be determined if E is known. If the Daniell cell is used, an approximate value of K will be found by calling E 1.08.

Apparatus. — Tangent galvanometer; Daniell cell; resistance box; commutator; wires for connections whose resistances are known.

Directions. — Connect the apparatus as shown in Fig. 77. Introduce resistance into the circuit until the deflection of the needle lies between the angles of 30° and 60°. Read by reversals and substitute in formula (4), considering $E = 1.08$. This will give approximately the value of the reduction factor of the galvanometer. If equation (4) be multiplied by any value of tan a (for this galvanometer), the strength of the current in amperes will be obtained.

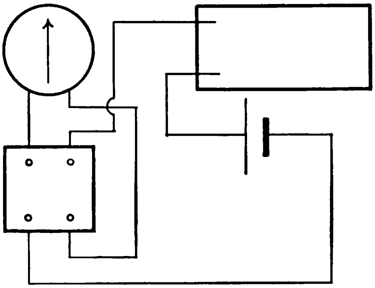

FIG. 77.

Experiment 106. To Determine the Reduction Factor of a Tangent Galvanometer. (An accurate method.)

(*For the Instructor.*)

Reference. — Stewart & Gee, Vol. II, pp. 249–252.

Apparatus. — A tangent galvanometer; a resistance box; a Pohl commutator or some other in which the reversals are nearly instantaneous; a chemical balance, sensitive to 0.1 mg.; a battery of four or five constant cells, like the Daniell; a clock or watch; two pieces of No. 14 bare copper wire about 2 m. long; a Bunsen burner; a battery jar; a solution of copper sulphate, density about 1.15; a support similar to that shown in Fig. 78; wires for connections.

Directions. — *a.* Clean the two pieces of bare copper wire by rubbing them, until bright, with emery or sandpaper. Then wind them into coils, one about 8 cm., the other about 4 cm. in diameter, straightening about 12 cm. of one end of each so that it will extend parallel to the axis of the coil. During the remainder of the experiment handle the coils by *this end only.* Clean the coils by first holding them in a Bunsen flame for a few seconds, to remove any oil which may have got on them from the fingers. When cool, place them in dilute sulphuric acid for about thirty seconds and then wash in distilled water; dry with clean blotting paper and then dip into strong alcohol. Dry again with blotting paper, after which hold them in a stream of dry, warm air. Weigh the smaller coil, which is to be the *cathode*, to within 0.1 mg. Mount the coils within the battery jar in some such manner as shown in Fig. 78, placing the smaller one inside and concentric with the larger. Cover both coils with the solution of copper sulphate.

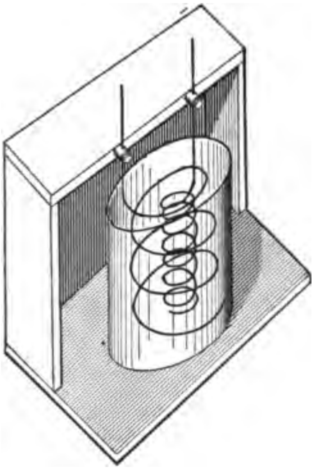

FIG. 78.

b. Connect the apparatus as indicated in Fig. 79. Observe the exact time the circuit is closed and allow the action to continue for at least one hour, keeping the current as nearly constant as possible by means of the resistance box. (The current will be constant if the same deflection of the galvanometer needle is maintained.) Read the galvanometer, which ought to show a deflection between 30° and 60°. Reverse the current through it every five minutes and record each reading. At the expiration of the time set for the continuance of the experiment break the circuit, remove the cathode coil, wash it first in ordinary water and then in distilled water, drying it as before. Again weigh, when it will be found that it has gained in weight. Care must be exercised that the cur-

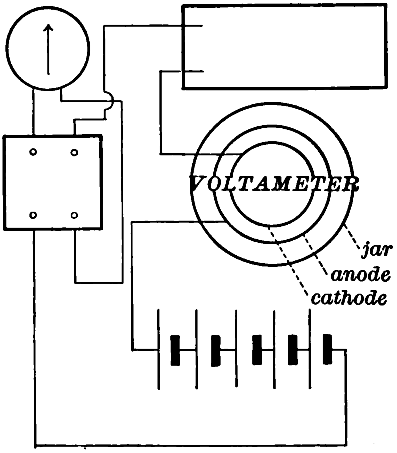

FIG. 79.

rent does not exceed a certain strength, as in that case the copper does not adhere but is deposited in the form of a powder. It has been determined, too, that the loss of weight of the anode coil cannot be taken as an accurate measure of the current, owing to the fact that this electrode is subjected to extra chemical action, which would increase the loss due to actual electrolytic action.

c. In order to determine the average current strength for the time the current was flowing, divide the increase of weight of the cathode (in grams) by the number of seconds which the current was flowing, and this quotient by 0.0003281, which is the amount of copper (in grams) deposited in one second by a current of one ampere (see "Lessons in Electricity and Magnetism," by Silvanus Thompson, p. 230).

d. If $x =$ the reduction factor of the particular galvanometer used, $C =$ the current strength found, and $D =$ the average deflection of the several readings, then

$$C : x = \tan D : \tan 45^\circ, \text{ or } C : x = \tan D : 1, \text{ and}$$

$$x = \frac{C}{\tan D}.$$

NOTE.—In this experiment and the one preceding, the reduction factor of a tangent galvanometer has been considered. Of course each coil of the instrument has its own reduction factor, which may be determined if desired.

Experiment 107. A Study of Induced Currents.

(For the Instructor.)

Reference. — Atkinson, pp. 90–95.

Discussion. — When a wire, *not connected with a battery* but otherwise so arranged (in a closed circuit) that a current might be sent through it, is made to pass through the field of a magnet in such a manner as to cut the magnetic lines of force, a current of electricity will thereby be caused to flow through the wire. Such a current is called an **induced** current and depends for its generation on the work done in causing the wire to cut the lines of force of the magnetic field. The essential feature in this experiment is that there must be relative motion between the cutting wire and the magnetic field. For clearness the experiment will be divided into four parts. Two pupils may profitably work together here, one to do the manipulating, the other to observe the mirror.

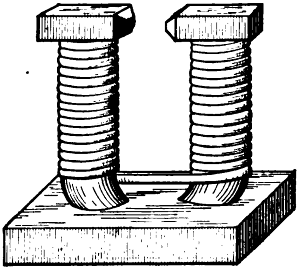
FIG. 80.

Apparatus. — A good D'Arsonval galvanometer; a "primary" and "secondary" coil; an insulated copper wire No. 18, about 2 m. long; a horseshoe electro-magnet of many turns of wire, pole pieces of soft iron being placed on top of the cylindrical cores as shown in Fig. 80; a strong bar magnet; a storage battery or a bichromate battery of at least five cells (a stronger current is better); a wooden hand clamp; a commutator.

NOTE 1. — If an astatic galvanometer is used, it must be placed two or three meters from the electro-magnet, and a longer wire used.

PART I. INDUCED CURRENTS PRODUCED BY MOVING A STRAIGHT WIRE IN A MAGNETIC FIELD.

Directions. — *a.* Connect the ends of the wire to the galvanometer posts, thus forming a closed circuit through the instrument, but *with no battery in the circuit.* Place the electro-magnet in a vertical position with the poles upward, and connect its terminals with the poles of the battery. Hold between the hands a portion of the middle of the wire which is connected to the galvanometer. Keeping this portion of the wire stretched between the hands, *quickly* pass it downward between the poles of the electro-magnet so that it shall cut the lines of force at right angles. Was the mirror of the galvanometer affected? How long does the current last in the wire and galvanometer?

Cause the wire to pass *quickly* in the opposite direction. Compare this effect on the mirror with that at first.

b. Move the wire *very slowly* through the field at right angles to the lines of force and note the effect on the mirror.

c. Repeat *b*, stopping and holding the wire for a few seconds between the pole pieces where the field is very strong. What effect is noticed?

d. Move the wire *across* the lines of force, first through a weak and then through a strong portion of the magnetic field. Which portion of the field causes the greater movement of the mirror?

e. Move the wire *parallel* with the lines of force as nearly as possible. What effect on the mirror? If no lines of force were crossed during the passage, how would the mirror be affected?

f. State the conclusions which may be drawn from the above operations as to the conditions which must exist for the production of a strong induced current.

PART II. INDUCED CURRENTS PRODUCED BY RELATIVE MOTION BETWEEN A COIL OF WIRE AND A BAR MAGNET.

g. Connect the "secondary" coil of wire in circuit with the galvanometer. Clamp the bar magnet in a vertical position with the South-Seeking end up. *Quickly* pass the coil down over the magnet to its *middle* point and hold it there until the mirror stops vibrating. The motion of the mirror indicated what? In which direction did it first move? Does it return to its original position? How long did the current last?

h. When the mirror has come to rest, *quickly* remove the coil from the magnet. What effect on the mirror? In which direction does it first swing? Does it return to its zero position?

i. *Slowly* pass the coil over the magnet as in *g.* What result? Remove the coil *slowly.* Result?

j. Allow the coil to remain stationary with the same end uppermost as in *g*, *h*, and *i*; remove the magnet from the clamp and pass *quickly* its South-Seeking end down into the coil. What effect on the mirror? *Quickly* remove the magnet. What effect? Compare the movements of the mirror noticed in *g*, *h*, and *j*.

k. Repeat *g* and *h*, having the North-Seeking end of the magnet uppermost, using the same end of the coil as in *g* and *h.* Does the mirror swing, at first, in the same direction as in the corresponding parts of *g* and *h*?

l. In order that a current may be induced in the coil what is necessary?

PART III. INDUCED CURRENTS PRODUCED BY THE MOTION OF A COIL IN THE FIELD OF A CURRENT.

m. Substitute for the magnet the "primary" coil in circuit with the battery, or with part of the battery and commutator, and repeat *g*, *h*, *i*, and *j*.

n. Change the direction of the current in the primary coil and determine whether this will affect the direction of the current in the secondary coil. It will be sufficient to proceed as in *m*, operation *g*.

PART IV. INDUCED CURRENTS PRODUCED BY CHANGES IN THE FIELD OF A CURRENT.

o. Place the primary coil inside the secondary and connect it through the commutator with the battery, the secondary coil being in closed circuit with the galvanometer. With no current in either coil there is no magnetic field. Close the circuit by means of the commutator. The primary coil is instantly surrounded by lines of magnetic force. What effect on the mirror?

p. Break the circuit. The lines of force about the primary coil are destroyed. What effect is noticed?

q. Reverse the current. The inner coil is now surrounded by lines of force running in the opposite direction. In which direction did the mirror swing? "Destroying" the field has what effect on the direction of the induced current? "Making" the field?

NOTE 2. — This experiment illustrates the principle upon which the dynamo and electric motor are constructed. A soft iron core is to be used in the primary.

Experiment 108. Electric Motor and Dynamo.

Reference. — Atkinson, Chap. VII.

Apparatus. — A "dissected" dynamo; a "dissected" motor; a galvanometer; a voltaic cell (several cells if necessary).

Directions. — *a.* "Assemble" (put together) the parts of the dissected motor and connect with the cell for a moment to see if it is in working order.

b. "Assemble" the parts of the dynamo.

c. Connect the galvanometer with the dynamo. Connect the motor and dynamo with a bell and then connect the cell with the motor. What evidence is there that a current is being generated by the dynamo?

d. As soon as the apparatus is evidently in good running order, "dissect" (take apart) the dynamo and motor and replace the parts as found.

SOUND AND LIGHT.

INTRODUCTION.

Experiment 109. A Study of Water Waves.

First Part. (For the Instructor.)

Apparatus. — A wave trough (see Appendix, p. 282); meter stick; water; sawdust; paddle.

Directions. — *a.* Fill the trough with water to a depth of 2 cm.; raise one end slightly, and when the water has become quiet, quickly lower it. A single wave will be started which will run to and fro the entire length of the trough several times, being reflected alternately at each end. Note the time required to make four trips along the trough, from end to end.

NOTE. — Several smaller waves may accompany the larger wave. This one may be most easily detected by noticing the sudden and decided rise of water at the end of the trough. This rise is so characteristic of the large wave that the smaller waves will never be mistaken for the large one.

b. Sprinkle a little sawdust in the trough and repeat *a* with depths of 4, 6, and 8 cm. of water, and determine the velocity of the wave in each case. Make at least three trials at each depth and record the mean.

c. Record results thus:

INSIDE LENGTH OF TROUGH ....

Depth of Water	No. of Trips	Time	Velocity per Sec. (in cm.)
2 cm.			
4 cm.			
etc.			

What relation does the depth of the water have to the velocity of the wave? To the height of the wave? Plot a curve, using depths of water as ordinates.

d. With the water 10 cm. deep, or with the surface even with the line on the glass, by use of the paddle, produce waves of different lengths and different heights. This is done by raising and lowering the paddle at various but uniform rates. What effect does varying the rate of motion of the paddle have on the length and height of the wave? How does the length of that part of the wave above the original water level, **the crest,** compare with the length of that part below this level, **the trough?** How does the amount of elevation compare with the amount of depression below the water level?

e. By properly timing the motion of the paddle **interference** can be produced between the train of waves reflected from one end and the train of waves started by the paddle, so that all *progressive* motion is destroyed, and only a seesawing motion remains. These waves are called **stationary waves.** Why?

f. Observe carefully and describe the motion of the particles of sawdust. In such waves is there any horizontal motion of the particles of water? If so, when does it occur, and in what direction with reference to the motion of the wave?

g. By suddenly changing the rate of motion of the paddle, endeavor to produce such interference that the wave will be nearly or quite destroyed. What conditions are necessary to produce this interference? What to produce a greater height of wave?

h. Assuming that sound and light are due to wave motion, what would be the necessary condition that sound might be added to sound to produce silence, or light added to light to produce darkness?

Second Part. (For the Pupil.)

Apparatus. — The ripple trough (see Appendix, p. 283); a strip of sheet tin about 5 cm. wide and 4 cm. longer than the internal width of the trough; a triangular piece of plate glass not quite as long as the trough is wide; a strip of window glass about 30 × 5 cm.

i. Fill the ripple trough to a depth of 1 cm. with water. When the surface has become quiet strike one end of the trough in a horizontal direction with the hand. Describe the results noticed.

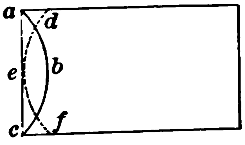

FIG. 81.

j. Place the strip of tin in the water at one end of the trough, one edge down, so that there will be a convex surface facing the incoming wave (see *a*, *b*, *c*, Fig. 81). Using the strip of window glass, start a wave across the trough towards the convex surface. Describe and give reason for the character and shape of the reflected wave.

k. Now place the strip of tin so that a concave surface will face the incoming wave, and repeat *j*.

l. Remove the strip, place the triangular piece of plate glass face down in the water across the middle of the trough. Start a wave as before. Describe and give reason for any change in the direction and shape of the wave after passing the glass. This illustrates refraction (see Exp. 128).

NOTE. — The results obtained in Part II of this experiment are analogous to reflection and refraction of sound and light.

SOUND.

Experiment 110. Wave Motion. (*For the Instructor.*)

Apparatus: — A rubber or spiral wire cord about 3 m. long; a pointer.

Directions. — *a.* Suspend the cord from a hook in the ceiling and fasten the lower end to a hook in the floor, or hold it to the floor by pressure with the foot, so that the cord will be subjected to a slight tension. With the pointer tap the cord near the lower end, timing the blows so that the cord shall vibrate as a whole, as shown in Fig. 82. Count the number of vibrations made in 30 seconds. Make three trials, take the mean of these and record in the table below.

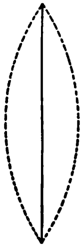

FIG. 82.

b. Tap the cord more rapidly until it vibrates in two **segments**, with a **node**, that is, a stationary point at the middle of the cord. Make three trials and record as before.

c. Similarly, cause the cord to vibrate in three and then in four segments, recording the numbers of vibrations as before.

d. Tabulate results as follows :

Trial	No. of Segments	Length of Segments	No. of Vibrations in 30 Seconds
1			
2			
etc.			

e. What is the relation between length of segment and number of vibrations in a given time?

Experiment 111. Cause of Sound.

Apparatus. — Tuning fork; tumbler of water; pith ball fastened to a thread; a small bell.

NOTE. — A tuning fork should never be struck on anything harder than soft pine wood, as otherwise a metallic twang is produced which serves to cover up, in part, the real sound. The fork may also be caused to vibrate by drawing a violin bow across one or both the prongs.

Directions. — *a.* Cause the bell to sound by striking it with a pencil or other light body, and while it is sounding suspend the pith ball so that it rests lightly against the bell. Result?

b. Tap the tuning fork on a piece of rubber, or something similar, and hold it near the ear. Result?

c. Tap the fork again and suspend the pith ball against one of the prongs. Result? Tap again and hold it lightly against the cheek. Result?

d. Tap again and dip the prongs about 1 mm. into the water. Result?

e. In all of this work sound was produced. What seemed to be the condition of the body while sounding? Judging from these experiments, what is the cause of sound?

Experiment 112. The Vibration of Plates. Chladni's Figures.

Apparatus. — Chladni's figures apparatus; violin bow; fine sand.

NOTE. — By changing the position of the bow and fingers, the figures produced can be varied almost indefinitely.

Directions. — *a.* Sprinkle sand lightly but evenly over the surface of the plate clamped in a horizontal position. Draw the bow vertically across one edge of the plate. If the bow is held correctly, a clear tone will be produced. Repeat two or three times, being careful to apply the bow at exactly the same place and with the same pressure. Result?

b. Press a finger against one edge of the plate and bow again. Repeat, pressing against the plate with two fingers. Result?

c. Draw each set of these figures. Notice that the tone varies with the figures, and also that the lines along which the sand settles are lines of no motion. These lines are called **nodal lines.** The vibrating parts are called **ventral segments.** Such figures are called **Chladni's figures.**

Experiment 113. Transmission of Sound. *(For the Instructor.)*

Apparatus. — Air pump; large receiver; dry voltaic cell; electric bell; cotton batting; a watch; a wooden rod.

Directions. — *a.* Connect the bell and voltaic cell so that the bell rings. Place them on a thick wad of cotton under the receiver of the air pump and exhaust the air as thoroughly as possible. Result? Rapidly admit air to the receiver. Result?

b. Place the watch at one end of the table and hold your ear at the other end. Result?

c. Hold one end of a wooden rod between the teeth while another pupil holds the stem of a vibrating tuning fork against the other end of the rod. Result? Repeat without the rod but with the fork the same distance away. Result?

d. What is the conclusion as to the transmission of sound in a vacuum? What is the sound medium in *a*? In *b*? In *c*?

Experiment 114. Wave Length and Velocity of Sound in Air.

Apparatus. — Tuning fork; glass tube about 2.5 cm. in diameter and about 1.2 m. long, closed at one end with a one-hole rubber stopper, in which is placed a glass tube (see Fig. 83). To the outer end of this tube is attached a rubber tube about 1.5 m. long, the free end being connected with a glass funnel; meter stick; water; retort stand with ring and clamp.

Directions. — *a.* Clamp the glass tube, open end up, in a vertical position, as in the figure. Support the funnel from the retort stand and pour in water until the water level is about 15 cm. below the top of the large tube.

Set the tuning fork in vibration and hold it at the open end of the tube, the two prongs being in a vertical plane, as in the figure. What effect does this have on the sound produced by the fork?

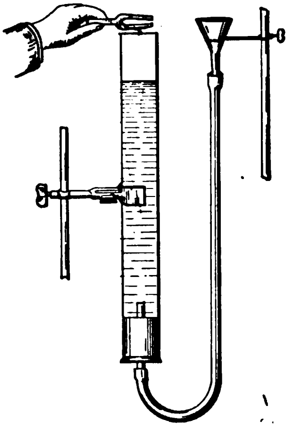

FIG. 83.

b. Again bring the vibrating fork close to the end of the tube and gradually lower (or raise) the funnel, listening for any change in the sound as the length of the enclosed air column is changed. Mark on the tube with a piece of wet paper the position of the water level when the loudest sound is produced.

c. Find and mark in like manner a second point of **reinforcement** of sound, which will give a much longer air column than before. The distance between the two positions of the water surface is equal to *one-half* of a wave length; or the length of the first air column plus 0.25 of the interior diameter of the tube is *one-fourth* of the wave length. Measure these two distances in both inches and millimeters and determine the complete wave length. Is the same result obtained by these two different methods?

d. From the wave length and the number of vibrations made by the fork in a second, calculate the velocity of sound in air, making the proper temperature correction thus:

Temperature Correction. The added velocity in air is 0.6 m., or 2 feet for each degree above 0° C.

e. Cause the fork to vibrate and, holding it near the ear, count the number of seconds that it can be heard. Cause it to vibrate again and, holding it above the tube as in *b* when the loudest sound was produced, or pressing the end of the handle on the table-top, count the number of seconds it can be heard. Are the results the same (nearly)? Explain.

f. Such reinforcement of sound as noticed in this experiment is called **resonance.**

NOTE. — Very satisfactory results may be obtained here and in Exp. 115 from a small fork, either " C " or " A," held over an Argand lamp chimney, dipping in a jar of water. Vary the length of the air column by raising or lowering the chimney.

Experiment 115. Interference of Sound.

Apparatus. — The tuning fork, glass tube, and connections of Exp. 114.

Directions. — *a.* Place the water surface at the position of reinforcement obtained in Exp. 114 *b*. Hold the fork as in Fig. 83, rotating it slowly on its axis above the mouth of the tube and note the effect. Now, starting from the position with both prongs held in a plane at right angles to the length of the tube, turn the vibrating fork through one-eighth of a revolution and state the effect; then through another eighth, etc., until one complete revolution results. Call these different positions 1, 2, 3, 4, 5, 6, 7, 8, and state the loudness of the sound in each position.

NOTE. — The change noticed is caused by **interference** of the sound waves started by the two prongs.

b. In which of these eight positions is there interference? Explain why.

c. Roll a piece of paper in the form of a cylinder, and while the fork, *vibrating strongly*, is in a position of least sound, slip the cylinder over one of the prongs without allowing it to touch the prong. Result? Remove the paper at once. Result? Explain.

Experiment 116. To Determine the Wave Length of a Tuning Fork by the Method of Interference of Sounds.

Apparatus. — As in Fig. 84; two Y-tubes; a funnel; a tuning fork; a glass tube, *E*, about 30 cm. long; rubber tubing as in the figure, one piece, *D*, about 25 cm. long, another, *H*, about 30 cm. long, and large enough to easily slip over the glass tube *E*. The rubber tube *FG* should be 75 or 100 cm. in length.

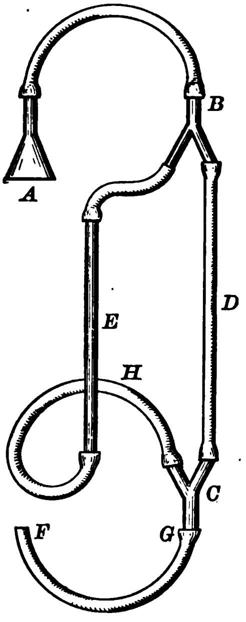

FIG. 84.

Directions. — *a.* Connect the tubing as shown in the figure. Let one pupil hold the free end of the tube *F* at his ear while another holds a vibrating fork before the open funnel at *A*.

NOTE. — It is evident that the sound waves divide at *B*, traverse each branch and unite again at *C*, reaching the ear through *GF*. If the tube *BEC* is one-half a wave length longer than *BDC*, the waves will meet in opposite phases at *C*, and little or no sound will be heard. Similar effects will follow if the difference is $\frac{3}{2}$, $\frac{5}{2}$, $\frac{7}{2}$, $\frac{9}{2}$, etc., of a wave length.

b. While the fork is sounding, pinch the tube at *H* or *D*. Note the intensity of the tone. Open the tube. Result? Now adjust the length of *BEC* by sliding the rubber tube over the glass tube *E*, until the sound produced when both tubes are open is weakest. Owing to the conductivity of the tubing, it will be impossible to extinguish all sound.

c. Measure the length of *BDC* and *BEC.* Find their difference. Compare this with the wave length of the fork as determined in Exp. 114.

Experiment 117. Sound Waves Made Visible.

Apparatus. — Cardboard about 12 cm. square; card about 5 cm. wide; soap-bubble solution; tuning fork mounted on a resonance box.

Directions. — Cut an opening about 4 cm. square in the middle of the cardboard. Support the cardboard in a vertical position. Dip the smaller card in the soap-bubble solution and draw it across the opening in the cardboard. After a few trials a film will be seen stretched across the opening. Sound a tuning fork placed on a resonance box and hold in front of the film. Result? Explain.

Experiment 118. To Determine the Vibration Rate of a Tuning Fork. (*For the Instructor.*)

Apparatus. — As in Fig. 85, consisting of a large tuning fork with a stylus of fine aluminum or brass wire fastened to one prong; a pendulum that beats one-fourth seconds, with a stylus extending below the bob; an adjustable support for holding the fork in a horizontal position; a plate of smoked glass about 10 cm. by 30 cm.; some sort of a carriage for the glass to rest upon, of the same size as the glass, with a string *A* fastened to one end.

Directions. — *a.* Place the smoked glass on the carriage, smoked face uppermost, and place both in position below the suspended pendulum. Adjust the height of the pendulum so that the stylus barely touches the smoked surface of the glass. Next place the tuning fork in its support and adjust its height in a similar manner. Arrange the pendulum and the fork so that the two styluses shall be as close to each other as possible, and so that they shall vibrate in parallel planes and each leave a scratch on the smoked glass.

b. Set the fork and the pendulum in vibration, and by means of the string quickly draw the carriage, with the glass, along under the vibrating fork and pendulum in a direction at right angles to their planes of vibration.

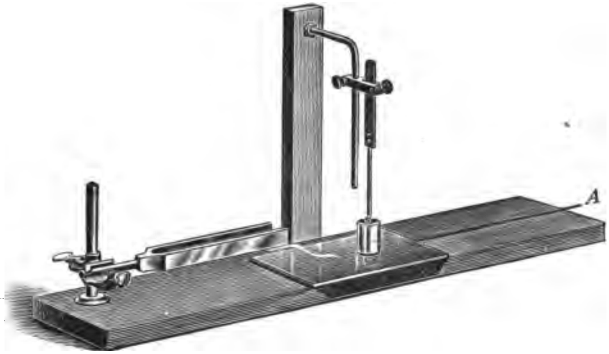

FIG. 85.

c. Count the number of vibrations recorded on the glass by the fork while the pendulum was making one *single* vibration. Use a magnifying glass if necessary. Calculate the number of *double* vibrations made by the fork in a second. Compare with the number stamped on the fork.

Error . . .. % of error . . ..

Experiment 119. Overtones. Sympathetic Vibrations. Beats.

(*For the Instructor.*)

Apparatus. — Sonometer, Fig. 86 (see Appendix, p. 283), with two spring brass wires No. 22, B. & S.; two 6 kg. weights; feather or sheet of paper; small strips of paper cut the shape and size of Fig. 87, or smaller, and folded in the middle, called "riders."

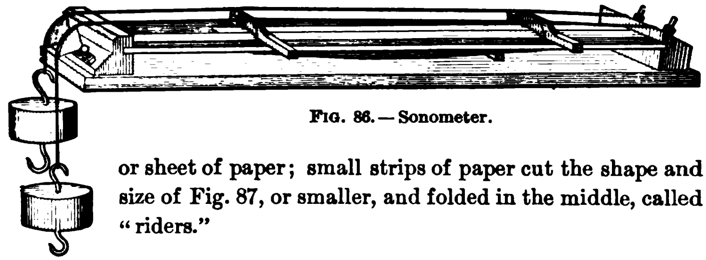

FIG. 86. — Sonometer.

Directions. — *a.* Place the sonometer on the table so that one end will extend 5 or 10 cm. beyond the edge. Place a large weight on the other end of the apparatus to hold it in place. Apply a tension of 6 kg. to one of the wires. Use 9 kg. if necessary to produce a good tone. In sounding a wire, pluck or bow it carefully near one end, and with the ear close to the wire, listen for the lowest tone produced. This is called the **fundamental** tone. Determine the fundamental of this string. Set the string vibrating and immediately touch it exactly in the middle with the finger, with a feather, or with the edge of a piece of paper. What is the difference in the pitch? Holding the finger or paper as before, against the middle of the wire, sound again. Result? Now, while sounding, and after touching with the finger or paper, drop one of the little paper "riders" on the wire exactly on the spot touched by the paper. Result? Repeat two or three times.

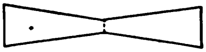

FIG. 87.

b. Sound the wire, and while sounding, touch the wire at a point one-third its length from one end. What tone results? Repeat, touching the wire one-fourth its length from one end. Result? The higher tones noticed here are called **overtones.** Place several riders on the wire at different intervals. See that one is located at *exactly* the middle of the wire, and another at *exactly* one-fourth the distance from one end. Now touching the wire at the point exactly one-fourth of the distance from the other end, sound the wire gently. Note the effect on the riders. Repeat several times until sure as to the results. Explain.

c. Tune the two strings to *perfect* unison. Place several riders on one string and cause the other to sound *very gently.*

d. Repeat, causing the string to sound loudly. After a moment, silence the first string and listen for a sound from the other one. Explain. Such phenomena illustrate **sympathetic vibrations.**

e. Change *slightly* the tension of one of the strings and repeat *d.* Cause both strings to sound at the same time. How does the sound now observed compare with that in *d*? The phenomena now noticed are called **beats.**

Experiment 120. Laws of Vibrations of Strings.

(For the Instructor.)

Apparatus. — Sonometer, as in the preceding experiment, with three spring brass wires, two No. 22 and one No. 28, B. & S. gauge; iron weights 3, 6, and 12 kg.; micrometer caliper.

Directions. — *a.* Tune the two wires of the same diameter in unison, so they will give a good musical tone; probably a tension of 6 kg. will be needed.

b. Having tuned the wires in unison, place a bridge under one wire a few cm. from the end, pluck the longer part and note any change of pitch. It may be necessary to press the shorter portion of the wire against the bridge with the finger in order to obtain a clear tone.

c. Length. Move the bridge until a length of wire is found whose tone is an octave above that of the other wire. Measure the length of both wires. Now move the bridge again until a tone is obtained two octaves higher than the first. Measure as before. Inasmuch as the higher tone of an octave is produced by twice as many vibrations per second as the lower tone, find from the results the relation between the number of vibrations per second and the length of the wires. State this relation in *f* below, as Law I.

d. Tension. With the same wires apply a tension of 3 kg. to one, and place the bridge under *both* wires at such a point that a good tone may be produced in the first wire. Now place a tension of 12 kg. on the second wire, and determine the musical interval between the tones produced by the two wires. State in *f*, as Law II, the relation here found between the number of vibrations per second and the tension.

e. Diameter. Substitute the No. 28 wire for one of the No. 22 wires. Place a tension of 3 kg. on each wire and *shorten both wires equally* by means of the bridge until a good tone is obtained from the thicker wire. Determine the musical interval as before. Find the diameter of the wires by the micrometer caliper. State in *f*, as Law III, the relation between the number of vibrations per second and the diameter.

f. Law I ....
Law II ....
Law III..

Experiment 121. Velocity of Sound in Brass and in Air. Kundt's Method. (*For the Instructor.*)

Apparatus. — The glass tube used in Exp. 114, one end closed with a stopper; a brass rod or tube about 1.5 m. long and 6 to 10 mm. in diameter, having a thin cork disk fastened to one end (this disk must slide inside the glass tube with slight friction); a wet cloth; a clamp for holding the brass rod parallel with the table-top, and at such a height that the glass tube when lying on the table may be readily slipped over it; a meter stick; cork dust.

Directions. — *a.* Clamp the brass rod at its middle. Place the cork dust inside the glass tube. Slip the glass tube over the disk on the end of the rod until about 25 cm. of the rod is within the tube. Distribute the cork dust evenly along the interior of the tube.

b. Rub the rod from the center towards the free end with the wet cloth. A shrill sound should be produced. Vary the length of the enclosed air column by sliding the tube, until when the rod is rubbed the cork dust is violently agitated and settles into groups of parallel ridges with spaces between. Unless the adjustment is quite exact the end ridges may not be perfect. Why is the cork dust agitated only at certain positions of the disk?

The groups of ridges mark the positions of ventral segments in the vibrating air column. The spaces between the groups of ridges are nodes. Is the cork disk on the end of the brass rod at a node or ventral segment of the air column? Is it at a node or ventral segment of the brass rod? Why?

c. The Vibrating Air Column. Measure the length of the enclosed air column and divide this length by the number of groups of ridges. This quotient (the average length of a ventral segment) will be one-half the wave length of the *air wave* caused by the sound produced. Why?

d. The Vibrating Rod. The point where the brass rod is fastened will be a node. As this is at the middle point, the length of the rod will be one-half the wave length *in brass* of the sound produced. Why?

e. Find the ratio of the wave length in brass to that in air. This will also be the ratio of the velocity of sound in brass to that in air. Knowing this, calculate the velocity of sound in brass (see Appendix, p. 313).

NOTE. — Instead of brass, rods or tubes of other materials such as glass, iron, steel, maple, pine, etc., could be used, in which case the velocity of sound in these substances could be computed.

LIGHT.

General Note. — In the following experiments four screens will be necessary. It is recommended that they be made of thin wood, 3, 6, 9, and 20 cm. square, and of a form as indicated in Fig. 88. The center of each screen should be about 15 cm. from the bottom of its base, *i.e.*, at the height of the top of a Bunsen burner, or a little higher. There should be a hole about 3 mm. in diameter at the center of the largest. For convenience the screens are called A, B, C, and D, beginning with the smallest. Always use a medium-sized flame unless directed to the contrary.

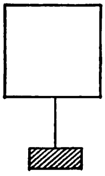

FIG. 88.

Experiment 122. To Determine the Character of Shadows.

Apparatus. — A darkened room; screens *B* and *D*; an ordinary flat gas or lamp flame.

NOTE. — If in the same darkened room others are performing the same or similar experiments, there should be some means provided for cutting off light coming from these experiments.

Directions. — *a.* Place the flame with its flat side toward the screen *D*, about one meter from it. Interpose screen *B* between them, adjusting it and the flame so that the shadow of *B* nearly covers *D*. Observe the light and dark parts of the shadow on *D*. The dark portion of the shadow is called the **umbra,** the lighter portion, or partial shadow, the **penumbra.** Make a sketch showing the arrangement of the apparatus and the shadow.

b. Move *B* so that the lighter part of the shadow cast by it will fall upon the hole in the middle of *D*. Look through this hole toward the flame. Do you see all of it? Why?

c. Arrange the screens so that the hole in the large one is covered by the dark part of the shadow. Look through the hole toward the flame. What do you see? Why?

d. Turn the edge of the flame toward the screens and note any change in the character of the shadow. Proceed as in *b* and *c*.

e. Under what conditions will an umbra be formed? A penumbra?

f. What would be the nature of the shadow

1) If the luminous body were a point?
2) If the luminous body had some magnitude but smaller than the opaque body, screen *B*?

3) If the luminous body were equal in size to screen *B*?

4) If the luminous body were larger than the screen *B*?

g. Why are shadows cast by electric arc lamps so sharply defined?

h. Make sketches showing the character of the shadow cast in each of the above cases.

Experiment 123. Images Formed through Small Apertures.

Apparatus. — A darkened room; a small gas or candle flame (an incandescent lamp will answer admirably); a piece of cardboard about 20 cm. square; screen *D* and another of the same size but with a hole 2 cm. in diameter at the center. Call this screen *E*. Horizontally across this screen and 25 mm. below the center should be a cleat or shelf 5 × 10 mm.; a piece of sheet tin 5 × 10 cm. with four holes in it along its longer axis — the first hole 1 mm. in diameter, 1 cm. from one end, the second 3 mm. in diameter, 2 cm. from the first, the third 10 mm. long by 1 mm. wide, cut horizontally 2 cm. from the second, and the fourth 2 cm. from the third, and of the same size cut vertically (thin cardboard can be made to answer in place of the tin); a pin or two to hold the tin in place.

Directions. — *a*. In a darkened room place screen *D* about 40 cm. from the flame, the center of which has the same height above the table as the center of the screen. Interpose screen *E* midway between, having the centers of the two screens and the flame in the same straight line and all parallel to each other. The shelf should be turned toward the flame. Place the piece of tin on the shelf so that rays of light will pass through the smallest hole and be intercepted by screen *D*. Observe the position of the image of the flame on *D*. Notice also its degree of sharpness or clearness.

b. Allow light to pass through the 3 mm. hole and note the nature of the image. How does it compare with that in *a*?

c. Pass light successively through the horizontal and vertical slits and note the shape of the image in each case. State the cause for the shape of the image in each instance.

d. With a pencil make two small holes through the cardboard about 1 cm. apart and allow the light to pass through them to the screen. Result? Vary the distances between the object, cardboard, and screen. Results? Make another hole between these two and repeat. Increase the number of holes to about 10 within an area of a square centimeter and repeat. What would be the effect if more holes were made in the same space? Why is it that images of objects are not seen when the light passes through large apertures or holes?

e. Make a sketch, showing why the images were inverted.

f. On what does the brightness of an image depend?

g. On what does the sharpness of an image depend?

Experiment 124. To Determine the Effect of Distance upon Intensity.

Apparatus. — A darkened room; screens *A*, *B*, and *C*; a candle or gas flame, the center of which has the same height as the center of the screens; a meter stick.

Directions. — *a*. Turn the gas flame very low, set *A* 15 cm. from the flame and adjust *B* so that the shadow cast by *A* shall exactly cover it. If *A* is now removed, it is evident that exactly the same light which was intercepted by it will now illuminate *B*; but as *B* has an area four times as great as *A*, the intensity of the illumination on unit surface of *B* is only one-fourth as great as that on *A*. That is, one sq. cm. of *A* received four times as much light as is now received by one sq. cm. of *B*. If 1 represents the intensity of the illumination on *A*, then 0.25 will be the intensity on *B*.

b. Measure carefully the distance of the flame from the illuminated surface of each screen.

c. Set *A* at a distance of 20 cm. from the flame and adjust *B* as before. Take all possible combinations of these screens, *A*, *B*, and *C*, with two different distances for each combination, always representing the intensity of the light on the screen nearer the flame by 1. Record the results in a table similar to the following:

Screens	DISTANCE OF FLAME		INTENSITY OF ILLUMINATION	
	From 1st Screen	From 2d Screen	On 1st Screen	On 2d Screen
A and *B*	15 cm.	?	1	0.25
A and *B*	20 cm.			
A and *C*				
etc.				

d. By a study of the data, formulate a law which states the relation existing between *distance* and *intensity of illumination.*

Experiment 125. To Determine the Relative Candle Power of Flames by Means of the Bunsen Photometer.

Apparatus. — A darkened room; screen *E*; five candles, alike.

Preliminary. — Over the hole in screen *E* paste or pin a piece of white unsized paper on which is a grease spot about the size of the hole. The paper warmed, with a drop of paraffine on it, makes a good translucent spot that answers the purpose. Call this screen so arranged a **Bunsen photometer.** Fasten four of the candles close together in a row on a block, and the fifth one on another block. Trim the wicks so that the flames are all of the same size.

Directions. — *a.* Set the single candle flame about 40 cm. from one side of the photometer, with the centers of the flame and oiled spot in the same horizontal line. On the opposite side of the photometer and in the same straight line place the row of four lighted candles parallel with the photometer and with their flames at the same height as that of the single candle. Locate the row of candles at such a distance from the photometer that the oiled spot is equally illuminated on both sides, *i.e.*, has the same appearance when viewed at the same angle from either side. The exact position may be determined by placing the photometer too far to the right, and moving it gradually to the left until both sides are apparently equally illuminated, and then by placing it too far to the left and moving it in the opposite direction until a place is reached where both sides are again apparently equally illuminated. A point midway between these two extreme positions should be the point selected as the correct position for the photometer. Make at least three trials.

Measure the distances from the screen to the candles. How do these results prove the Law of Intensity as found in Exp. 124?

NOTE 1.—The room should be darkened, and light from all other sources, including other experiments, thoroughly cut off by screens.

Discussion. — Since the intensity of illumination (Exp. 124) varies inversely as the square of the distance from the source of light, and directly as the intensity of the source, the amount of light that falls on each side of the oiled spot should be equal to the candle power of the source divided by the square of the distance of such source from the screen. Equating these two quantities, and forming a proportion, it will be found that the lesser light is to the greater as the square of the distance of the lesser light from the screen is to the square of the distance of the greater light from the screen.

It should be found, in the above test with the candles, that the four candle flame was twice as far from the screen as the single flame when the intensity of illumination was the same on both sides of the screen.

b. After proving the ratio of intensities of the two known sources of light in *a*, find the **candle power** of an oil lamp, gas light, or incandescent light as compared with the single candle used in *a*.

NOTE 2.—Another plan of adjustment is as follows: Place two plane mirrors, about 10 × 15 cm. each, one at each side of the screen, forming an angle with each other which is bisected by the plane of the screen. Vary this angle until an image of the oiled spot can be seen in each mirror without moving the eye.

Experiment 126. The Laws of Reflected Light.

Apparatus. — A plane mirror about 10 cm. by 15 cm. cemented in a vertical position to a block of wood, or held vertically by a string or rubber band passing horizontally around them; a protractor; four pins; a piece of paper about 20 × 30 cm.

Directions. — *a.* Across the middle of the narrow way of the paper draw a straight line, *MN* (Fig. 89), and place the mirror on edge, with its back or reflecting surface, *P*, on and parallel with this line. In front of the mirror, about 8 cm. and 10 cm., respectively, and about 12 cm. apart, set two pins vertically as at *A* and *B*. Set a third pin at *C* exactly in line with *A* and the image of *B* seen in the mirror at *B'*. Set a fourth pin at *D* in line with *B* and the image of *A* at *A'*. Locate a point *F* in line with *B* and its image *B'*.

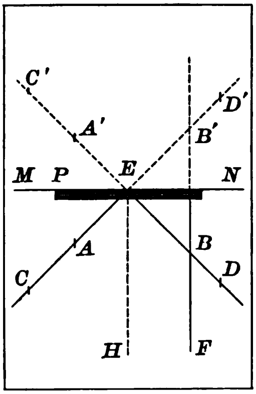

FIG. 89.

Caution. — For accurate results locate *C*, *D*, and *F* as far from the mirror as possible, and make the angle between *CA* and *DB* nearly a right angle.

b. Remove the mirror and draw lines *CA* and *DB* intersecting in *E* at the line where the mirror stood. Draw *EH* perpendicular to *MN*. Produce the line *FB* till it meets the line *CA* produced at *B'*. Then proceed as follows:

c. With a protractor measure *BEH*, the **angle of incidence**; and *AEH*, the **angle of reflection.** How do they compare in size? State this as Law I of Reflected Light.

d. An image is a **real** image if it can be shown on a screen. It is **virtual** in all other cases. *B′* is the point where the virtual image of *B* was seen. How far back of the mirror was it? Compare this distance with the distance of *B* in front of the reflecting surface. State this as Law II of Reflected Light.

e. In case of plane mirrors, what kind of an image is seen and where is it located?

Experiment 127. To Determine the Character and Position of an Image Produced by a Spherical Mirror.

Apparatus. — A darkened room; a concave and a convex spherical mirror of known focal lengths; meter stick; screens *C* and *D*; some "object" to study, as a small gas flame.

Directions. — *a.* In a dark room, with the mirror and flame always vertical and parallel to each other, and with their centers at the same height above the table, proceed as follows.

I. WITH A CONCAVE MIRROR.

b. With the flame at a distance of about 60 cm. from the mirror, hold screen *C* between the flame and the mirror and a little to one side of the line connecting their centers. Move it back and forth between the flame and the mirror till a distinct image of the flame is obtained on the screen. Change the positions of the flame and screen until a distinct image is obtained on the screen when both are side by side at the *same distance* from the mirror.

The flame is now approximately at the **center of curvature** *C* of the mirror. The middle point of the reflecting surface of the mirror is called its **vertex,** *A*. The line connecting the center of curvature and the vertex is called the **principal axis.** Halfway between the center of curvature and the vertex and on the principal axis is the **principal focus** *F*. Any line passing through the center of curvature other than the principal axis is called a **secondary axis.** It is customary to call the flame the **object.** Is the image as now seen larger or smaller than the object? Is it erect or inverted? Where is it with reference to the center of curvature, principal focus, and vertex? Is it real or virtual?

c. Tabulate the results in the form below. In this form, "Position" means erect or inverted; "Size" means larger or smaller than the object; "Kind" means real or virtual.

d. Move the object farther from the mirror and relocate the screen. Answer the same questions as in *b*. As the distance between the object and the mirror increases, what change occurs in the size and location of the image? If the object should be moved far enough away so that the rays of light would be practically parallel, where would the image be found, and what would be its size?

e. Place the object between *C* and *F*. Find the image, using screen *D*. Answer the questions asked in *b*.

f. Place the object at *F* and repeat.

g. Place the object between *F* and *A*. Hold the screen in various positions. Do you find an image? Look into the mirror. Do you find an image? Describe it. Can it be obtained on a screen? Is it real or virtual?

CONCAVE MIRROR.

Trial as in	Object	Image			
	Location	Position	Size	Location	Kind
b	at *C*				
d	beyond *C*				
e	between *C* and *F*				
f	at *F*				
g	between *F* and *A*				

II. WITH A CONVEX MIRROR.

h. Investigate a convex mirror and place the results in a form similar to the above. Do not be surprised if fewer results are found than with the concave mirror.

i. To represent on paper the above work, draw an arc of a circle with a radius of about 4 cm. Let this arc represent the mirror. Draw the principal axis. Represent the object by an arrow instead of a flame. Locate the object as in *b*, on the principal axis, however, instead of at one side, as was necessary in the experimental work, and draw a secondary axis through one end of the object. The image of this point must evidently lie in this same line. Draw a second line from the same point of the object to the mirror parallel to the principal axis. It is evident, from what was learned in *c*, that a ray of light reaching the mirror in this line will be reflected through *F*. Therefore from this point on the mirror draw a line through F and extend it if necessary till it meets the line first drawn. The intersection of these two lines will locate the image of the point under consideration. Repeat the construction for the other end of the arrow. *Letter* and *name* the principal points.

j. Draw a diagram for each result under the concave and convex mirror, showing the position of the mirror, object, and image.

k. How do images with concave and convex mirrors compare in kind?

Experiment 128. Refraction.

Apparatus. — A two-quart basin; water; a coin; a piece of plate glass; a pencil or a piece of wire; a glass prism of small angle; a 90° prism; a candle; a teaspoon or some similar irregular object to place in water; a biconvex lens; a beaker; a meter stick; sunlight (or gas flame).

Directions. — *a.* Place the coin in the basin. Stand so that the edge of the basin shall just hide the coin. In the remainder of the work consider in every case the *farther edge* of the coin. *Without moving*, watch the coin while another pupil pours water into the basin till it is nearly full. Is the coin now visible? Without moving, let this pupil measure the height of your eye above the table; also the horizontal distance of the eye from the edge of the basin; and the horizontal distance from the edge of the basin to the point in the surface of the water where the coin now seems to be; also the horizontal distance from the edge of the basin to the real position of the coin.

b. With these measurements draw *to scale* a diagram showing the course of the ray from the real position of the coin to the eye. Where did the bend occur? Draw a line from this point perpendicular to the surface of the water; was the ray bent toward or away from this perpendicular as it passed from the coin to the eye? This bending of a ray of light is called **refraction.**

The ray between the point of its origin, the coin, and the point where the bending occurs is called the **incident ray**; between the bend and the eye it is called the **refracted ray.** The angle included between the incident ray and the above perpendicular line is called the **angle of incidence**; that between the refracted ray and the same perpendicular, the **angle of refraction.** Suppose the ray to have passed from the eye to the coin, *i.e.*, from air into water, it would have had identically the same course.

c. Is a ray of light passing from water to air bent toward the perpendicular mentioned in *b*, or away from it? Supposing it to pass from air to water, which way will it be bent? If the ray be parallel to the above-mentioned perpendicular, it will not be bent at all.

NOTE. — As the ray passes from water to air, is the angle of incidence or that of refraction the greater? It is evident that as the angle of incidence increases, the angle of refraction increases more rapidly, and will shortly reach 90°, *i.e.*, the refracted ray will barely skim along the surface of the water. The corresponding angle of incidence (much less than 90°) is called the **critical angle** (of water and air). If now the angle of incidence be made anything greater than the critical angle, the refracted ray will not be able to get out of the water at all, but will be *reflected* back into the water, according to the Law of Reflection. This result is called **total reflection,** because the reflection is so much more complete than in ordinary cases. This principle produces much better results in scientific work than can be obtained by the finest mirrors. It may be illustrated as follows.

d. Place some irregular body, such as a spoon, in a beaker of water and look up through the side of the beaker and through the water. Is the upper part of the spoon seen? Is a reflection of the lower part seen? Remove the spoon, place a lighted candle on the opposite side of the beaker, and again look up through the side of the beaker and water at its reflection. With the 90° prism place an object near one of the sides adjacent to the 90° angle, and look through the other at its image in the third side, the side opposite the 90° angle. Do you find the image in all three cases surprisingly distinct? Why?

e. Hold the piece of plate glass and the wire in contact with each other in front of the face. Look through the glass at the wire held vertically, allowing the wire to project somewhat above the top of the glass. Turn the apparatus back and forth on the wire as a vertical axis. Notice the apparent distortion of the wire. Draw a diagram showing the path of a ray of light passing from the wire to the eye when looking at the glass perpendicularly, and another when it was in such a position that you were looking obliquely at it. With the apparatus in this oblique position, gradually move the wire away from the glass in such a direction that it may still be seen through the glass as well as above it. Show by a diagram the path of a ray passing to the eye from the wire when in this position. Is the entire path of the ray a single straight line? Is the path of the ray between the wire and the glass, that of the **incident ray,** parallel with the path between the glass and the eye, that of the **emergent ray?** Would the same be true if the two surfaces of the glass were not parallel to each other?

f. In order to answer the last question, exchange the plate glass for the prism of small angle, holding the wire parallel with the three parallel edges of the prism; and with the wire extending vertically above the prism, proceed as in *e*. How does a prism affect rays of light passing through it? With respect to the prism, in which direction is the bending, toward its thicker or thinner portion, *i.e.*, toward its **edge** or its **base**?

g. In the lens, where is the thicker part? Reasoning from this, in what direction would rays be deflected when passing through the lens? Hold the lens in the sunlight (or, in its absence, at some distance, say 2 or 3 m., from a flame). On the other side of the lens move a screen back and forth until the circle of light (or image of the flame) is distinct and as small as possible. How are the rays of light affected? This point at which the rays converge is called the **principal focus** of the lens.

Experiment 129. Index of Refraction of Glass (and Air).[1]

Apparatus. — A piece of plate glass about 7 cm. square and 0.6 cm. thick. Two opposite edges should be ground perpendicular to the faces, parallel to each other and polished; a sheet of cross-section paper; three pins; dividers; metric scale.

Directions. — *a.* Place the plate glass (Fig. 90, *G*) flat on the paper *P* with its polished edges parallel with the lines on the paper. Stick a pin upright at the point *A*, close to one of the polished edges of the glass. Stick another pin at *B*, close to the other polished edge.

b. Look with one eye from the position *C through* the whole width of the glass at pin *A*. Move the eye toward *D*, looking all the time through the glass at the pin. It will soon be noticed that the pin *A* seen *through* the glass is not in the same direction from the eye as the same pin seen *over* the glass. That which is seen through the glass is an image of the real pin. It is upon this image that the attention should be fixed.

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[1] The plan of this exercise is due to Mr. F. M. Gilley, of the Chelsea, Mass., High School.

c. Continue moving the eye in the general direction of *D*, keeping it, however, about 30 cm. from the glass, until the image of pin *A* is just hidden behind pin *B*. Then place the third pin at *D*, in the same straight line with the eye, pin *B*, and the image of pin *A*.

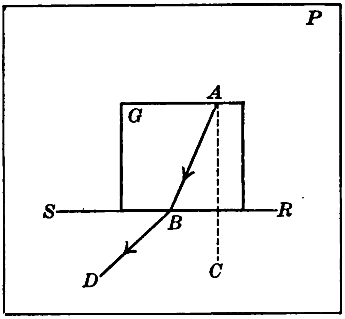

FIG. 90.

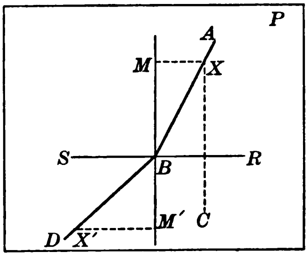

FIG. 91.

d. Draw a fine pencil line *RS* upon the paper close to the edge of the glass in contact with pin *B*. Then remove the glass and pins.

NOTE. — With reference to *Light*, a "denser" medium is one which presents more resistance to the passage of light than does a "rarer" medium.

e. The line last drawn marks the position of the refracting surface. We are to consider the "denser" medium, plate glass, above the line *RS*; and the "rarer" medium, air, below. Connect *A* with *B* (Fig. 91), and *B* with *D* by fine lines. The line *AB* shows the direction of a certain ray from *A* within the glass. The line *BD* shows the direction of this same ray after it left the glass at *B*. Now draw a line, *MM'*, perpendicular to the refracting surface at the point of emergence, *B*. From *B* lay off equal distances on *BA* and *BD*, thus locating the points *X* and *X'*. Draw lines perpendicular to *MM'* from *X* and *X'*. *XM* is the sine of the angle *XBM*, and *X'M'* the sine of the angle *X'BM'*. The angle *XBM* is the angle of incidence; the angle *X'BM'* is the angle of refraction (from glass to air). The **index of refraction** is the quotient of the sine of the angle of incidence divided by the sine of the angle of refraction; therefore $XM \div X'M'$ = the index of refraction from plate glass to air. What is your result? Error .... % of error ....

NOTE. — The numerical result obtained in this experiment is the reciprocal of the Index of Refraction given in Table XLII, p. 314.

Experiment 130. Determination of the Foci of a Lens.

Apparatus. — A biconvex lens; a biconcave lens; supports for the lenses (see Appendix, p. 284); screen *D*; a gas or candle flame; a meter stick.

Directions. — *a.* Hold the biconvex lens in the sunlight so that a circle of light is cast on the screen. Are the rays from the sun practically parallel? Move the screen to and fro until the circle is as small as possible. The screen is now at the **principal focus** of the lens. Measure and record the distance from the screen to the lens. Call this distance the **focal length** of this lens.

b. Using the *same* lens obtain on the screen the image of some distant object, as a tree or chimney. Describe this image. Measure the distance of the screen from the lens. How does this distance compare with the result obtained in *a*? If there is no sunlight, this method of determining the focal length will answer in place of *a*. Are the rays here practically parallel?

c. Adjust the flame and the screen on opposite sides of the lens, so that the image is the same size as the flame, and both are equally distant from the lens. The flame and screen are now at points called **secondary foci.** Describe the image formed. Measure the distance of the lens from the image. How does this distance compare with that obtained in *a* and *b*?

d. Place the flame between the principal and secondary foci of the lens. Move the screen until a sharp image is obtained. Describe the image.

e. Let the screen and flame exchange places. Describe the image as before. These two points are called **conjugate foci.** How many other pairs of conjugate foci are there for this lens? Is there more than one pair of secondary foci for this lens?

f. Place the flame well beyond the secondary focus and move it by successive steps towards the lens, at the same time moving the screen so as to retain the image. Describe the results noticed.

g. Try the converse of *a* or *b*, that is, place the object at the principal focus and investigate the results. Place the flame nearer the lens than the principal focus. Is any image obtained on the screen? Look through the lens at the flame. Describe the image seen. While looking through the lens, gradually move the lens away from the object. Adjust so that the object, lens, and eye have the same relative position as the object, lens, and screen in *c*. Describe results.

h. Repeat *a*, *b*, *c*, *d*, *e*, *f*, and *g*, using the concave lens.

i. Draw a diagram for *b*, *c*, *d*, and *g* for both the convex and concave lenses. Use in each diagram two rays, one passing near the upper edge of the lens, the other near the lower edge. Show the position of the lens, object, and image. Letter and name the principal points. Use arrows to represent the object and image.

j. What is the general effect of a convex lens on rays of light? Does it cause them to converge or diverge? What is the effect of a concave lens?

Experiment 131. To Illustrate the Compound Microscope and Refracting Telescope.

Apparatus. — Two small biconvex lenses of about 4 cm. and 8 cm. focal length, respectively; one biconvex lens of 10 cm. diameter and 40 cm. focal length; one biconcave lens; supports for the lenses (see Appendix, p. 284); screen *D*; gas flame.

Directions. — *a*. Place the flame in front of and near the lens of 4 cm. focal length. Turn the flame down until it is quite small and arrange the apparatus so that the centers of the flame and the lens will be at the same height. Hold the screen so that the lens shall be between it and the flame. Adjust the relative positions of screen, lens, and flame until a sharp, clear image of the flame is formed on the screen.

b. Place the lens of 8 cm. focal length just beyond the screen and nearer to it than its focal length. Now remove the screen and look through the second lens toward the first. Adjust the second lens so that a sharp, clear image of the flame is seen.

c. Describe this image. Is it real or virtual? How does it differ from the image seen in *a*? Draw a diagram showing the paths of the rays of light. This illustrates the principle of the compound microscope. The lens nearer the object is called the object glass; the other, the eyepiece.

d. Repeat *a*, *b*, and *c*, using the lens of 40 cm. focal length in place of the one of 4 cm. Obtain on the screen the image of some distant object, instead of the flame. It may be well to place a screen with a circular hole about 5 cm. in diameter close to the large lens to avoid **chromatic aberration.** This illustrates the principle of the **refracting** telescope, the lenses being named as in *c*. All telescopes in ordinary use are refracting telescopes; *reflecting* telescopes are seldom used.

e. Repeat *d*, using the lens of 40 cm. focal length as the object glass and the biconcave lens as the eyepiece, placing the eyepiece near the screen, between it and the object glass. This illustrates the principle of the **opera glass.**

Experiment 132. Color and the Spectrum. (*For the Instructor.*)

References. — "Light," by Lewis Wright, Chaps. IV, VI, VII; "Art of Projecting," by Dolbear; Hopkins's "Experimental Science," Chap. XXII.

Apparatus. — An oxyhydrogen projecting lantern with screen; two carbon disulphide prisms; a mounted convex lens of 40 cm. focal length; Bunsen burner; a black card with a slit 2 × 30 mm.; a black card about 10 × 12 cm.; pieces of colored glasses, red, blue, green, etc., about 8 × 10 cm.; a rotator with Newton's color disk; two pieces of glass tubing.

Directions. — *a.* Remove the objective from the lantern, and fasten the card containing the slit on the end of the tube in place of the objective. Arrange the convex lens so as to focus the slit on the screen. Turn the lantern through an angle of about 70° and adjust the lens and one of the prisms beyond it so that a distinct spectrum is produced on the screen.

b. Now place the second prism about 1 cm. from the first so as to intercept the dispersed rays and bend them back again. Notice that the image of the slit is seen and that it is *white.*

c. Gradually interpose the black card at one side between the two prisms so as to suppress part of the spectrum formed by the first. Notice that the image is now a colored one. How is the color produced in this case?

d. Remove the second prism. Hold the red glass over the upper half of the slit. Results? Repeat, using each of the other colored glasses in turn. Results?

e. Remove the lime from the holder and hold the glass tubing in one edge of the lantern flame so that a bright yellow flame due to the combustion of sodium in the glass is obtained. Is the same kind of a spectrum produced as in *a*? If not, describe it. This **bright line spectrum** is due to the combustion of sodium vapor.

NOTE. — Instead of the glass tubing, crystals of some Lithium, Barium, Strontium, Calcium or Potassium salt could be burned, thus producing the characteristic spectra of those metals.

f. Replace the lime in its holder and obtain its spectrum. At the same time place the glass tube in the oxyhydrogen flame. Describe the spectrum produced. Without disturbing this arrangement, place a non-luminous Bunsen flame between the slit and the lantern flame and obtain a second sodium flame with it and the other glass rod. What change in the spectrum? Why? Now hold the black card between the lantern flame and the Bunsen flame so as to cut off the light of the lantern from the upper part of the slit. What effect is produced? This illustrates **absorption spectra** and **bright line spectra.**

g. Remove the glass tubing, Bunsen burner, slit, prism and lens, and insert the objective. Rotate the Newton's disk in the field of the lantern. Result?

Hold the colored glasses one at a time in front of the objective, and notice which colors on the stationary disk are unchanged in each colored light. What kind of light is necessary for colors to be seen in their true relation? What is color? How caused?

NOTE. — This experiment may be varied indefinitely, according to time and circumstances. With slight modifications it may be performed with either an electric lantern or a porte-lumière.

For further valuable information on this subject, see "Light," by Wright, above mentioned.

Spring Balance Correction.

(*See also p. 269.*)

Suppose a cord to be attached to the *ring* of a spring balance and the balance to hang vertically from the cord so that a force may be applied to the hook in a downward direction. Evidently the stress in the cord is simply the weight of the balance. Does the pointer so indicate? Is a correction then necessary?

APPENDIX I.

CONSTRUCTION OF APPARATUS.

Zero Point of a Balance — Balance Reading by Vibrations.

MUCH time is lost in weighing if one waits for the pointer to come to rest at its **zero point** each time. A much more rapid method of determining the zero point is by finding where the pointer *would* come to rest, as follows:

Raise the beam to its bearings and note that the pointer vibrates on either side of what will finally be its zero position. On account of friction, resistance of the atmosphere, etc., the amplitude (distance it swings) grows less at each successive swing. Avoiding parallax (Exp. 1, Note), which may be done by placing a small mirror just behind the pointer and taking care that the pointer covers its own image at each observation, read its position at five successive turning points. Suppose they are:

	To the left.	*To the right.*
	(1) 1.4	
	(3) 1.1	(2) 2.6
	(5) 0.7	(4) 2.2
Sum	3.2	4.8
Mean	1.1	2.4

The true zero point will therefore be $\frac{2.4-1.1}{2} = 0.6$ space to the right.

This explanation supposes the zero of the scale to be in the middle and the scale to read in either direction. If the zero was at one end instead of the middle, it would be necessary in the above fraction to add the two means instead of subtracting one from the other.

Determine the zero point of a balance, using five swings of the pointer while it vibrates through about three scale divisions as above. Then determine it again with three swings only; then once more with seven swings. The more observations the more accurate the result.

Now, using five swings, determine the zero point while the pointer vibrates through about seven divisions and again through about ten. Finally allow the pointer to come to rest. Does this last result agree closely with the previous determinations? If not, which is the more satisfactory? Why?

The zero point should be thus determined each day. Two observations will be sufficient for this purpose.

Sensitiveness of a Balance.

Determine the zero point, with no load, by the method of vibrations. Then place a 1 cg. weight in one pan and determine the new point of rest in the same way. The difference between these two is called the **sensitiveness of the balance** for zero load. From this may be determined the value of each division of the scale *for this load.*

In the same manner test the balance for loads (in each pan) of 1 g., 10 g., 100 g., 1000 g.

Determine in each case the point of rest with the load considered, then the change produced by the addition of 1 cg.

Plot the results on cross-section paper (see Introduction, p. xxii), using the load as abscissa and the sensitiveness as ordinate.

In this way a balance may be used for more accurate work than the smallest weight available would otherwise allow.

Spring-Balance Corrections.

A spring balance is made to read correctly in a vertical position, with the weight of the draw bar and hook exerted on the spring. In any other position it is incorrect. If the position in which it is used is such that the pointer is in contact with the face plate at the end of the slot, the amount of the correction may be determined (approximately) by using a more sensitive balance and noting on it how great a force is necessary to bring the pointer to the zero point.

If the pointer is not in contact with the face plate at the end of the slot, whether it is above or below the zero point, the amount of the correction (the distance of the pointer from the zero point) may be determined by inspection. For example: if the pointer, in the given position of the balance, is at the 10 g. line, then the balance will always read 10 g. too much in this position; if this pointer be the same distance "above" the zero line, then the balance will always read 10 g. too little in this position (see p. 266).

Frequently it is advisable to select some other position of the pointer as the "zero point" (see Exp. 14, Note 1), in which case it is unnecessary to make any correction.

Screw and Nut for Use in Exp. 14, Elasticity of Extension.

The screw and nut can be made from a cabinet maker's wood screw. If size No. 10 or larger is used, two screws and nuts can be made from one wood screw by cutting the affair in two at *AB* (see Fig. 92). A hole should be bored through the wood at *C* of the same size as the one at *D*.

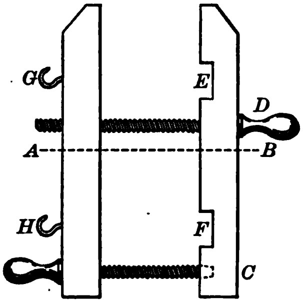

FIG. 92.

Notches to fit the edge of the table-top should be cut as indicated at *E* and *F*. Each nut should have a strong hook fastened to it, as shown at *G* and *H*.

Apparatus for Exp. 16, Elasticity of Torsion.

In order to eliminate the greater part of the friction in Exp. 16, the apparatus should be arranged as follows: A bicycle hub *A* (ball bearing) is mounted in a block of wood which may be clamped near the edge of the table-top (or the hub may be mounted as part of the clamp itself, as in Fig. 93). The hub must be mounted high enough in the block or clamp, so that the pulley *B* will clear the table-top. Attached to one end of the hub is a brass socket *C* with an internal diameter of about 1 in., in which the rod to be tested may be centered and fastened by means of three set screws. The other end of the rod is to be fastened to a clamp, which may be moved along the edge of the table-top, thus allowing various lengths of the rod to be tested. Attached to the same end of the hub, and concentric with it, is a circular grooved disk or pulley *B*, about 6 in. in diameter, furnished on one of its flat surfaces with a circular scale *D* divided

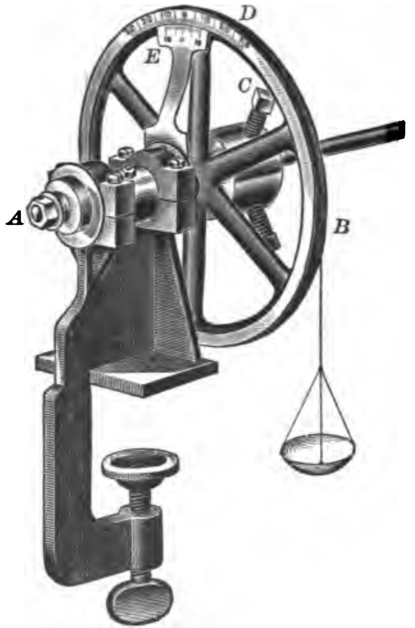

FIG. 93.

in degrees and provided with a vernier *E.* This circular scale and vernier is to be read precisely as in Exp. 2, the only difference in their use being that in this case the vernier is *fixed* and the "large scale" *moves.* If there is no vernier, a fixed point must be located in its place, from which to reckon, and it would be well to use larger weights than are mentioned in Exp. 16. On the circumference of the pulley is a cord carrying a scale-pan, in which are to be placed the weights (masses) to produce the torsion in the rods.

Yarn Tester for Exp. 17, Tensile Strength of Wires.

The yarn tester (see Fig. 94) is a modified form of the spring balance specially arranged for such work as indicated in this experiment. It differs from the ordinary balance as follows: it is fastened in place in a horizontal position and *reads correctly* in this position; the pointer is loose and is pushed along by the draw-bar, so that it remains where it is when the wire breaks, instead of flying back. This does away with practically all the danger and inconvenience in using the ordinary spring balance. The yarn tester should read to about 15 kg. or 30 lbs. As furnished by the manufacturers, it has a small loose pulley instead of a hook. This loose pulley should be replaced by a *fixed* grooved cylinder with a diameter of 25 mm., or more, and a length of about 10 mm., as shown in Fig. 19. A stud with a narrow vertical slit in it should be attached to the draw-bar, as shown. The end of the wire may then be fastened by tying a single knot in it and slipping it into the slit in the stud. An English binding post may be used instead of the stud with slit.

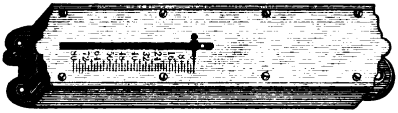
FIG. 94.

Apparatus for Exp. 19, Falling Bodies.

It is very difficult to obtain satisfactory results in an experiment on falling bodies. There are serious objections to all of the ordinary methods. For older pupils, probably the Atwood's Machine is the most satisfactory method for studying this subject, but for less elaborate work, and quite as satisfactory on the whole, the inclined plane offers itself. Then, too, the problem of the inclined plane occurs so frequently throughout the subject of Physics that further discussion of the principles involved is quite in place. For the inclined plane a stretched wire is not satisfactory, as it is both theoretically and practically impossible to prevent a decided change in the inclination of such a wire as the body rolls down. This difficulty can be thoroughly overcome by using for the plane a track formed by fastening together, side by side, two brass or glass tubes supporting one end, and allowing a sphere to roll down the "groove" thus formed. For the sphere, use a steel ball about two inches in diameter made for a "ball bearing."

The sphere may be held at the top of the plane by an electro-magnet, so arranged that its circuit shall be broken at the same instant that the pendulum circuit is closed. There is, however, so much residual magnetism in the ordinary iron core that the sphere is decidedly tardy in beginning its motion. For this reason, the method of Exp. 19 is preferred.

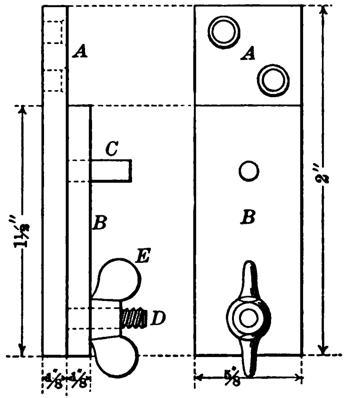

FIG. 95.

Suspension Clamp for Pendulum, Exp. 20.

The two pieces, *A* and *B* (Fig. 95), are made of brass of the dimensions given. The front piece *B* has two holes, as shown, which are a little greater in diameter than the stud *C* and screw *D*, so that it can be easily moved. *C* and *D* are soldered to *A*. *E* is a thumb screw. *A* has two countersunk holes for screws to fasten the clamp to a proper support.

In adjusting the length of the pendulum the stud *C* can be used as a fixed pulley, over which the thread or wire can be moved.

Apparatus to Illustrate Boyle's Law, Exp. 35.

This apparatus consists of a vertical support of pine wood (see Fig. 30) about 8 ft. by 6 in. by 1 in. Along the entire length of one face are secured three strips in the positions and with the dimensions shown in section in Fig. 96. In each of the grooves formed by the three strips moves a slide about 15 in. long, which can be held in any desired position by means of a thumb screw passing through it and pressing against the front of the vertical support, the nuts of the thumb screw being sunk into and screwed to the back of each slide. On the slide at the left (see Fig. 30) is mounted a thick-walled gas analysis tube (closed at the top) about 5 mm. in internal diameter and 35 cm. long, graduated for 30 cm. of its length. On the other slide is fastened in a similar manner a plain glass tube of the same diameter as the other, but 50 cm. long and open at the top. These two tubes should be so mounted that they are as close to each other as possible as they slide past one another. The lower ends of these two tubes are drawn out to receive the ends of a cloth-inserted (pressure) rubber tube about 6 mm. in internal diameter and 250 cm. long.

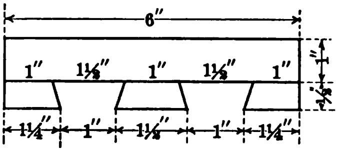

FIG. 96.

Enclosing the ends of the rubber tube and fastened to the lower end of each slide, is a grooved block, about 3 in. long and 1 in. square. The purpose of the block is not only for holding the ends of the rubber and glass tubes in place, but also for preventing any strain upon the glass tubes as the rubber is bent, when one slide is near the top and the other near the bottom of the support. Along the middle of the central guide is secured a millimeter scale extending the entire length of the support, the zero line being at the lower end. Enough mercury must be placed in the tubes, so that when the middle of one is opposite the middle of the other both tubes will be half filled. The apparatus may be fastened to the wall, or it may be mounted on a horizontal triangular base, the three corners being provided with leveling screws.

Copper Boiler (Harvard "Apparatus A").

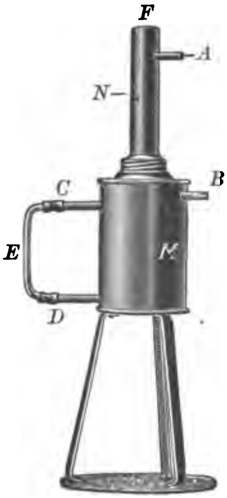

FIG. 97.

The boiler used in Exp. 58 (Fig. 97), and for much other work in Heat, is a modified form of the Harvard "Apparatus A." It consists of a copper cylinder *M* about 4 in. in diameter by 6 in. high, supported on three legs each 7 in. long. The cylindrical top *N* is about 6 in. by 1½ in. It is fastened to the body of the boiler by a threaded connection, fitting to an asbestos packing. The side tubes *A* and *B* are 1 in. long. *C* and *D* are about 3 in. long. *E* is a bent glass tube fastened to *C* and *D* by rubber tubing, and serving as a water gauge. *F* may be closed by a No. 8 one-hole rubber stopper. The hole in the stopper may be closed by a piece of glass rod. The tubes *A* and *B* are to be provided with short rubber tubes and pinchcocks for closing them. A "dipper" usually accompanies the boiler for work in specific heat.

A safety gauge should be provided in the form of a glass tube bent as shown in Fig. 32, p. 98, and containing mercury instead of water. It should be 15 or 20 cm. long and about half filled with mercury. Connect *B* of Fig. 32 with *B* of Fig. 97. Of course if the gauge be made with longer arms, longer columns of mercury may be used and a greater range of observation may therefore be obtained. In that case too there will be less danger of the mercury being blown out of the gauge by a little careless use.

Linear Expansion Apparatus, Exp. 64.

This apparatus consists of a tinned or galvanized iron tube about 1 in. in diameter and 20 in. long, closed at each end with a cork. A brass rod (or tube) about ¼ in. in diameter and a little longer than the tube is contained in it and projects through a hole in each cork. At each end of the tube, and on opposite sides, extending at right angles to its length, is inserted a short tube about ¼ in. in diameter. A thermometer is inserted nearly to the 100° mark in the cork at one end of the steam jacket. The tube thus arranged is set horizontally on a rack. Steam is to be passed into the

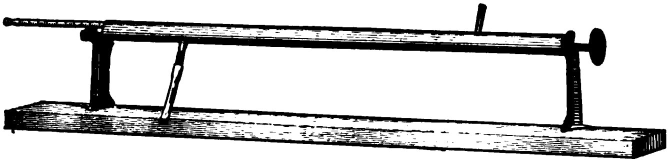

FIG. 98.

apparatus at the upper opening, while some vessel should be placed in position to catch the condensed water at the exit. A screw is partly driven horizontally into one of the end uprights of this rack, at such a height that the end of the brass rod shall press against it when the apparatus is set up. On the upright, at the other end of the apparatus, is fastened a micrometer screw so that the end of the screw can touch the free end of the rod. The micrometer and the screw in the other support are connected in circuit with an electric bell or telegraph sounder and a battery.

If this form of apparatus is not at hand, a micrometer caliper can be used in place of the micrometer screw by clamping the caliper to the support so that the *head* can touch the free end of the brass rod.

The Construction of a Magnetoscope, Exp. 74.

A magnetoscope consists of a magnet so suspended as to swing freely in a horizontal plane. To construct an inexpensive magnetoscope, use a watch-spring magnet, suspended by a silk fiber or a silk raveling so it will hang horizontally. Suspend this from the stopper of a 4 oz. flask or small bottle. Have the magnet as long as possible without touching the glass. It may be preferable to omit the bottle.

The Construction of an Electroscope, Exp. 85.

Secure a glass bottle or flask about 10 cm. in diameter, having a neck of about 2.5 cm. opening. Through the center of a rubber stopper, which will close the bottle tightly, pass a No. 16 copper wire 15 cm. long. To the upper end fasten a smooth lead bullet or other metal ball about 1.5 cm. in diameter. The lower end of the wire should be bent into the form shown in Fig. 99, the horizontal part being about 1 cm. long. Cut from a sheet of gold or aluminum leaf a piece about 8 cm. long and 0.6 cm. wide. This can best be done by allowing the gold leaf to remain between the leaves of the "book" and cutting through the paper and sheet of metal with a pair of *sharp* scissors. If there is any "burr" on the piece thus cut, place the burr side *down* on a flat piece of metal. In order to mount the leaf a room must be used which is as free as possible from air currents. The utmost care must be used in handling the leaf. Use only very smooth tools in working with gold or aluminum leaf and be sure that they are perfectly dry. The gold beater's wooden pincers are the best. Carefully remove the upper piece of paper from the leaf by overcoming the adhesion with the aid of a knife blade thrust between. Now place on the lower side of the horizontal arm of the wire shown in Fig. 99, a *little* varnish or shellac and gently bring it down at right angles upon the center of the leaf. On cautiously raising the wire it will generally be found that the leaf will come away with it, leaving the paper behind. The wire and leaves are now to be transferred to the bottle.

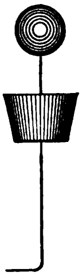
FIG. 99.

The Construction of an Electrophorus, Exp. 86.

One of the best materials to use in the construction of an electrophorus is vulcanite. This can be of any thickness greater than 2 mm. and of a diameter greater than 5 cm. (see *A*, Fig. 100). The vulcanite may stand on a metallic "sole" or base *B*. An excellent substitute for the vulcanite is sealing wax or beeswax which has been melted and run into an ordinary pie tin to the depth of 5 mm. or more. A metallic disk *C* is necessary to

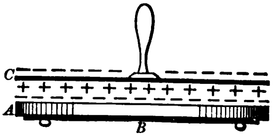

FIG. 100.

complete the apparatus. At the center of the disk is fastened an insulating handle of vulcanite or glass.

The Amalgamation of Battery Zincs.

New zinc with a smooth surface is easily amalgamated by first dipping it into a solution composed of one part, by volume, of sulphuric acid and six parts of water, allowing it to remain for a few seconds for the purpose of removing the oxide of the metal on the surface. Now place a drop of mercury on the zinc and rub it all over with a cloth. If the zinc has a rough surface, more trouble will be experienced in properly amalgamating it. Such zinc should be kept in dilute acid, as above mentioned, for some time before applying the mercury.

One of the most convenient methods of amalgamating zinc is to dip it in a solution of chloride of mercury made by dissolving 5 cc. of mercury in a mixture of 60 cc. of nitric acid and 210 cc. of hydrochloric acid. This solution should be prepared and the zinc amalgamated out of doors or under a hood, as nitrous acid fumes, which are very obnoxious, are given off during each operation. This fluid should be kept in a glass-stoppered bottle ready for use when required.

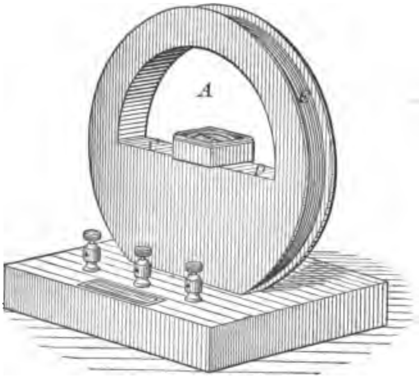

FIG. 101. — Tangent Galvanometer.

Tangent Galvanometer.

The base of this apparatus (Fig. 101), 12″ × 14″ × 1½″, is made of whitewood or clear pine, well seasoned and kiln dried. In the upper side a groove is cut 1⅜″ wide and 1″ deep at the center, so that the circular piece will snugly fit into it. The circular piece is 14″ in diameter and 1⅜″ thick, with a rectangular groove *E* ¾″ wide and ¾″ deep in its edge. In the circular piece a portion *A* is cut out. This cut-out portion should extend ¼″ below the center of the circular piece.

Wind upon this groove 20 turns of No. 18 "annunciator" wire, leaving sufficiently long ends for the connections. Upon this coil wind *in the same direction* another coil of 50 turns of No. 26 silk-covered double magnet wire. If desired, additional coils of greater or less turns of wire can also be used. Pass the free ends of the wire through a hole made in the center of the groove in the base and insert the circular piece in this groove, keeping the surface *CD* horizontal. When finally adjusted, draw the wires tight, and, laying them in grooves on the under side of the base, lead them to the binding posts. Connect the coils in series, one end of each coil to the middle post.

The magnetic needle can be made from a watch spring and should be about ¾″ long, with a hole drilled at the center. Over this hole cement a glass cap made from thin-walled glass tubing. A cement for this purpose is mentioned on p. 284 of this appendix. For a pointer, an aluminum, glass, or quartz wire, cemented at right angles to the needle, can be used. At the exact center of the surface *CD* insert a fine needle, point uppermost, and at such a height that the magnet, when suspended, will be at the center of the circular piece and free to turn.

The box for the magnetic needle is 4″ square and ¾″ deep, with a thick cardboard bottom. In the bottom of this box a mirror with a hole in the center should be slipped over the upright needle and fastened in place with brass tacks. A paper circle 3″ in diameter, graduated in degrees from 0° to 90° in both directions from each end of one diameter, should be so fastened to the mirror that its center is vertically in line with the needle point, and its 0° diameter parallel with the plane faces of the circular piece. (These paper circles can be obtained of E. Ritchie's Sons, Brookline, Mass.) The box should have a glass top to protect the magnetic needle from air currents.

Great care should be observed that all these adjustments are *exactly* and *correctly* made, as on them depends the accuracy of the instrument.

Leveling screws are desirable but not necessary if the work has been well done. The instrument should be well coated with oil and varnish. Any carpenter can make the parts.

The Construction of a Set of Resistance Spools.

The resistance spools of Exps. 91 and 96 consist of five spools of wire wound so as to prevent self-induction and mounted on a wooden block. It is preferable to have the wires wound on divisions of a single long spool placed horizontally with binding posts and connections as in Fig. 102 (the "Chicago" form).

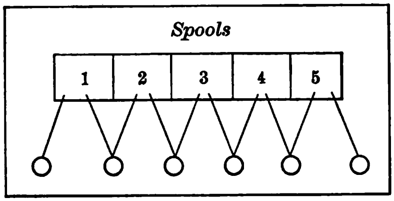

Fig. 102.

Spool No. 1 contains 10 m. of silk-covered copper wire No. 22 B. & S.
Spool No. 2 contains 10 m. of silk-covered copper wire No. 28 B. & S.
Spool No. 3 contains 20 m. of silk-covered copper wire No. 22 B. & S.
Spool No. 4 contains 20 m. of silk-covered copper wire No. 28 B. & S.
Spool No. 5 contains 10 m. of silk-covered German silver No. 22 B. & S.

The Construction of a Daniell Cell.

The Daniell is a very constant, two fluid cell. It consists in part of a glass jar containing a saturated solution of copper sulphate (blue vitriol). In this is placed a porous cup containing dilute sulphuric acid, 1 part acid to 20 or 25 parts of water by volume. A well-amalgamated zinc plate is placed in the porous cup, a copper plate in the copper sulphate solution. The liquid inside the porous cup should stand slightly higher than the copper sulphate outside when ready for use, and somewhat more than 1 cm. below the top of the cup. Suitable cells may be made from heavy glass tumblers about 10 cm. tall and 7 or 8 cm. in diameter. The zinc plate should be about 10 × 3 × 0.5 cm. The copper plate about 15 × 10 cm. The porous cup of unglazed porcelain about 10 × 5 cm. After a porous cup has once been used it should not be allowed to dry until after it has been thoroughly soaked in water, as crystals are likely to form within its pores and crack it. If allowed to dry, it should be boiled thoroughly in water before using again.

This cell has an E. M. F. of about 1 volt (1.08 volts when fresh and clean). When first set up it should be short circuited for a short time, 10 or 15 minutes. It should be kept on closed circuit, through a resistance of from 20 to 100 ohms, when not in use, to prevent osmosis.

Explanation of the D'Arsonval Galvanometer.

A very desirable form of the D'Arsonval galvanometer (see Fig. 103) has been designed by Mr. Charles H. Smith, of the Hyde Park High School (Chicago). (See Exp. 97.)

A model of the D'Arsonval galvanometer may readily be constructed as follows :

Make a coil one or two centimeters in diameter of fifty or more turns of copper wire, No. 30 or smaller, leaving a meter or more of the wire at each end free for suspension. Set a strong horseshoe magnet with its poles upward and suspend close to the poles, between them if possible and parallel with them, the coil of wire. The longer the suspending wires the more sensitive the apparatus will be. Send a current from any kind of cell through the wire and study the results.

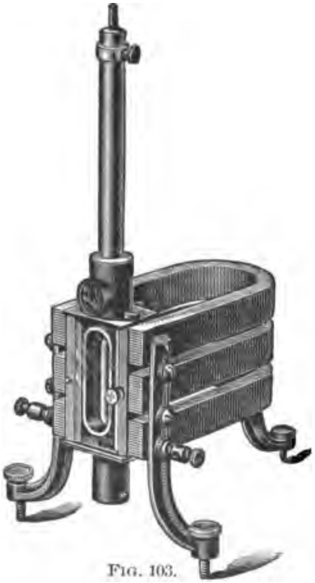
FIG. 103.
D'Arsonval Galvanometer.

Temperature Coil.

A temperature coil consists of fine, bare copper wire wound in grooves around a hollow hard rubber cylinder. When in use the coil is immersed in water.

Wave Trough.

The wave trough of Exp. 109 (see Fig. 104) is a rectangular box with plate glass sides, 10″ × 2½″ × 60″, open at the top. The base and ends are made of oak, 6″ wide and 1¾″ thick. The base should be about 7 ft. long. The edges of one side of the base and ends should be rabbeted as shown, 1¾″ wide and ½″ deep. The end pieces should have a tongue on one end to fit into grooves cut crosswise of the base. The ends should be firmly braced. The wood work should have several coats of boiled oil to prevent absorption of water. Set the glass in white lead and fasten it in place by strips of moulding.

A black line should be painted on the outside of one of the glass sides 10 cm. above the floor of the trough and parallel with it. The plate glass 10″ × 60″ × ¼″ can be obtained of Hooker & Co., W. Randolph and Clinton Sts., Chicago, for about $1.50 per piece. Total cost of materials about $5.

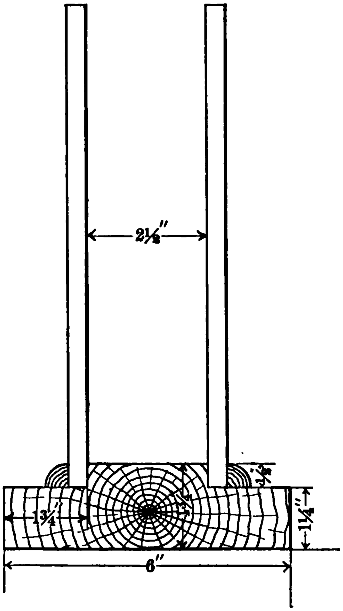

FIG. 104.—Section of Wave Trough.

Ripple Trough.

The ripple trough is a rectangular box about 17″ × 25″ and 1¾″ high, with glass bottom, and open at the top. The sides are made of oak 1¾″ × 1¾″, with a rabbet on the inside ¼″ × 1½″. For the bottom, use window glass 14″ × 22″.

The Sonometer.

The base, Fig. 105, is made of clear pine 42″ × 6″ × ⅞″. The two upright pieces are ⅞″ thick, 3½″ high on the inside, 3″ on the outside edge and 6″ long. On the inside, 2″ from the bottom, a rabbet ¼″ deep is cut, into which a clear straight grained pine board, 32″ × 6″ × ¼″ is to be glued and fastened with small nails. All material used must be well seasoned and kiln dried. Nails for fastening the wires can be driven into

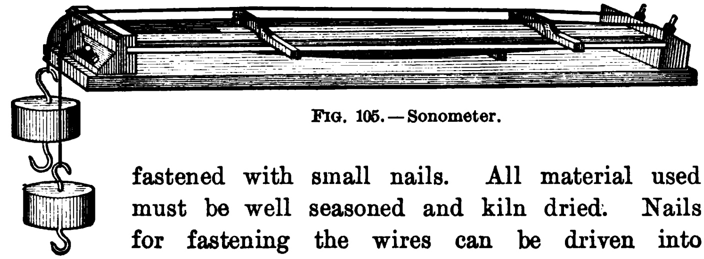

FIG. 105.—Sonometer.

one end of the base. The apparatus should be provided at the other end with pulleys over which the wires may be stretched. Canvas sacks filled with sand can be used for the stretching weights.

Lens Support.

The lens support of Exp. 130 consists of a wooden base *M*, and upright *N*, Fig. 106. The base is 4″ × 4″ × ¾,″ with a slot, *A*, 1″ × 4″, extending through the middle of one side to fit a meter stick lying on the table. One end is rabbeted across this groove, 2½″ wide and ½″ deep. An upright 7¾″ × 2½″ × ⅝″ is fastened to the base in this rabbet. In the upright is a hole 1¼″ in diameter at such a height that its center is about 6″ above the lower surface of the base.

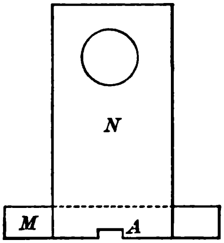

FIG. 106.

For the large lenses of 40 cm. focal length the upright may be about 4″ wide, the hole being 2¼″ in diameter.

Cement for Fastening Glass to Iron.

A good cement for fastening glass to iron is made by soaking white glue in water until soft. Pour off any excess of water, add one-fourth its volume of glycerine or molasses and heat gently.

To Drill Holes in Glass.

Use an ordinary metal drill, or the broken end of a file will answer if the edges are sharp. Keep the glass wet at the point where the hole is being drilled, with a solution made of 1 oz. camphor gum, 1¾ oz. turpentine, and ½ oz. ether.

To Clean Mercury.

Caution. — If mercury touches gold or silver jewelry it will destroy it in time. If taken care of at once the mercury may be dissolved with *strong* nitric acid. If the jewelry be *plain*, not set with stones, etc., it may be driven out by heat. The best plan will be to take it to a jeweler at once.

If the impurities consist only of ordinary dust and dirt or of water or other liquids, they may be removed by placing the mercury in a bottle, covering with the finger and inverting, when the impurities will rise to the top and the clean mercury may be allowed to run out at the bottom.

If the impurities consist of various metals the only satisfactory method of cleaning is by distillation, using an iron still. This is the most satisfactory method of cleaning in all cases.

However, if there be only a small quantity of other metals present it may be removed very well as follows: Fill a burette, supported in a vertical position, with dilute nitric acid. Allow the impure mercury to slowly drop into the acid, using a funnel with its stem drawn out to a fine point so that the mercury will fall in minute drops, or place a paper in the funnel with a pin hole in it. The mercury can be drawn off by the stop-cock at the bottom and rinsed under a faucet.

Acetylene.

In laboratories where illuminating gas cannot be obtained, gasolene or acetylene gas can be used. Acetylene makes a very brilliant white light and is especially adapted for lantern work. It makes a very good substitute for the oxyhydrogen light. For heating purposes a specially made Bunsen burner is necessary.

APPENDIX II.

TABLE I. — NUMBERS FREQUENTLY USED.

(For Metric Equivalents, see Tables II–VIII).

$\pi = 3.14159.$ $\pi^2 = 9.8696.$ $\frac{1}{\pi} = 0.3183.$ $\sqrt{\pi} = 1.7724.$

AREAS AND VOLUMES.

Circumference of a circle (radius r)	$= 2\pi r.$
Area of a circle	$= \pi r^2.$
Surface of a sphere	$= 4\pi r^2.$
Volume of a sphere	$= \frac{4}{3}\pi r^3.$
Surface of a right circular cone (altitude h and radius of base r)	$= \pi r\left(\sqrt{h^2 + r^2} + r\right).$
Volume of a right circular cone	$= \frac{1}{3}\pi r^2 h.$
Surface of a right cylinder (altitude h and radius of base r)	$= 2\pi r\,(r + h).$
Volume of a right cylinder	$= \pi r^2 h.$
Volume of a frustum of a cone	$= \frac{1}{3}h\left(B + b + \sqrt{Bb}\right).$

WEIGHTS OF VOLUMES.

1 cu. ft. of water at 4° C. weighs	62.425	pounds.
1 cu. ft. of water at 16⅔° C. weighs	62.321	pounds.
1 cu. ft. of air at 0° C. weighs	0.080728	pounds.
1 cc. of air at 0° C. and 76 cm. weighs	0.0012932	grams.
1 liter of hydrogen at 0° C. and 76 cm. weighs	0.08969	grams.

TABLE II. — SOME EQUIVALENTS OF THE C. G. S. SYSTEM.

One dyne at New York = 0.00102 grams.
One poundal = 13825 dynes.
One foot-poundal = 421390 ergs.
One gram weight = 981 dynes.
One lb. avoirdupois = 4.445 × 10^5 dynes.
One kg. weight = 981000 dynes.
One atmosphere (760 mm. and 0° C.) = 1012630 dynes per sq. cm.
One atmosphere (30 in. and 0° C.) = 1015300 dynes per sq. cm.
One calorie = 4.17 × 10^{10} ergs.

TABLE III. — REDUCTION OF MILLIMETERS TO INCHES.

mm.	in.	mm.	in.
100	3.93708	710	27.9532
200	7.87415	720	28.3469
300	11.81124	730	28.7406
400	15.74832	740	29.1343
500	19.68539	750	29.5280
600	23.62247	760	29.9217
700	27.55955	770	30.3155
800	31.49663	780	30.7091
900	35.43371	790	31.1029
1000	39.37079	800	31.4966

EXPLANATION OF TABLES IV–VIII.

In the next five tables a number in any vertical column indicates the number of units of the denominations, shown at the top, in one unit of the term used in the corresponding horizontal line.

TABLE IV.[1] — EQUIVALENTS OF UNITS OF LENGTH. (Sloane.)

	Millimeter	Centimeter	Meter	Kilometer	Mil	Inch	Foot	Yard	Statute Mile	Geograph. Mile
Millimeter	1	0.01	0.001	0.000001	39.37079	0.039371	0.003281	0.0010936	0.0000006	0.0000007
Centimeter . . .	10	1	0.01	0.00001	393.7079	0.3937079	0.032809	0.010936	0.000006	0.000007
Meter	1000	100	1	0.001	39370.79	39.37079	3.28090	1.09363	0.000621	0.000716
Kilometer	1000000	100000	1000	1		39370.79	3280.899	1093.633	0.621382	0.716330
Mil	0.025399	0.0025399	0.0000254		1	0.001	0.000083	0.000028		
Inch	25.3994	2.53994	0.025399	0.0000254	1000	1	0.083333	0.027777	0.0000158	0.000015
Foot	304.7945	30.47945	0.304795	0.0003048	12000	12	1	0.333333	0.000189	0.000164
Yard	914.3835	91.43835	0.914384	0.0009144	36000	36	3	1	0.000568	0.000493
Statute Mile . . .		160931.4	1609.314	1.609314		63360	5280	1760	1	0.868382
Geographical Mile .		185329	1853.29	1.85329		72963.2	6080.27	2026.76	1.1516	1

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[1] See Explanation, p. 288.

TABLE V.[1] — EQUIVALENTS OF UNITS OF AREA. (Sloane.)

	Square Millimeter	Square Centimeter	Circular Mil	Square Mil	Square Inch	Square Foot
Square Millimeter . . .	1	0.10	1973.6	1550.1	0.00155	0.0000108
Square Centimeter . . .	100	1	197.361	155.007	0.155007	0.001076
Circular Mil	0.000507	0.0000051	1	0.78540	0.0000008	
Square Mil	0.000645	0.0000065	1.2733	1	0.000001	
Square Inch	645.132	6.451	1.273238	1000000	1	0.006944
Square Foot	92898.9	928.989			144	1

TABLE VI.[1] — EQUIVALENTS OF UNITS OF VOLUME. (Sloane.)

	Cubic Inch	Fluid Ounce	Gallon	Cubic Foot	Cubic Yard	Cubic Centimeter	Liter	Cubic Meter
Cubic Inch	1	0.554112	0.004329	0.000578		16.3862	0.016386	
Fluid Ounce	1.80469	1	0.007812	0.001044		29.5720	0.029572	
Gallon	231	128	1	0.133681	0.00495	3785.21	3.78521	0.003785
Cubic Foot	1728	957.506	7.48052	1	0.037037	28315.3	28.3153	0.028315
Cubic Yard	46656	25852.6	201.974	27	1	764505	764.505	0.764505
Cubic Centimeter . . .	0.061027	0.033816	0.000264	0.000035		1	.001	0.000001
Liter	61.027	33.8160	0.264189	0.035317		1000	1	0.001
Cubic Meter	61027	33816	264.189	35.3169	1.3080		1000	1

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[1] See Explanation, p. 288.

TABLE VII.[1] — EQUIVALENTS OF UNITS OF WEIGHT. (Sloane.)

	Grain	Pound Avoirdupois	Ton	Milligram	Gram	Kilogram
Grain	1	0.000143		64.799	0.064799	0.000065
Pound Avoirdupois . . .	7000	1	0.000447		453.593	0.453593
Ton		2000	1			907.186
Milligram	0.015432	0.000002		1	0.001	0.000001
Gram	15.4323	0.02205		1000	1	0.001
Kilogram	15432.3	2.20462	0.001102	1000000	1000	1

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[1] See Explanation, p. 288.

TABLE VIII.[1] — EQUIVALENTS OF UNITS OF WORK AND ENERGY. (Sloane.)

	Erg	Gram-degree C.	Kilogram-degree C.	Pound-degree C.	Pound-degree F.	Gram-centimeter	Kilogram-meter	Foot-pound	Horse-power-sec.
Erg	1					0.001019			
Gram-degree C. .		1	0.001	0.002205	0.003968	42353.5	0.4235535	3.06355	0.00557
Kilogram-degree C.		1000	1	2.2046	3.9683		423.535	3063.55	5.57
Pound-degree C. .		453.59	0.45359	1	1.8		192.114	1389.6	2.52653
Pound-degree F. .		251.995	0.251995	0.555556	1		106.730	772	1.40364
Gram-centimeter .	981	0.000235				1	0.00001	0.000072	
Kilogram-meter .	$98.1 \times \overline{10}^6$	2.36108	0.002361	0.005205	0.009370	100000	1	7.23328	0.013152
Foot-pound . . .	13550000	0.326425	0.000326	0.000720	0.001295	13825.3	0.138253	1	0.0018182
Horse-power-second	$1242 \times \overline{10}^9$	179.486	0.179486	0.3957	0.71243		76.0392	550	1

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[1] See Explanation, p. 288.

TABLE IX. — COEFFICIENT OF ADHESION FOR SOME BODIES. (Winckelmann.)

P = weight lifted, in kilograms.
F = area of surfac in sq. mm.
$a = \frac{P}{F}$ = coefficient of adhesion.

PLATES OF SOME METAL		SOLID BODIES AND FLUID	
Substance	**a**	**Substances**	**a**
Antimony . . .	0.0000009	Glass and Mercury .	0.000018
Bismuth	0.0000010	Glass and Water . .	0.000006
Copper	0.0000013	Zinc Amalgam and Mercury . . .	0.000050
Lead	0.0000009		
Tin	0.0000006		
Zinc	0.0000010		

TABLE X. — COHESION OF SOME LIQUIDS. (Gay-Lussac.)

A glass disk 118.366 mm. in diameter was used. The weight required to lift is given below.

Substance	Density	Temperature	Weight Required to Lift Disk, in Grams	Dynes
Alcohol	0.8196	8° C.	31.08	30458.40
Alcohol	0.8596	10.	32.87	32212.60
Alcohol	0.9415	8.	37.15	36407.00
Turpentine . . .	0.8695	8.	34.10	33418.00
Water	1.0000	8.5	59.40	58212.00

TABLE XI. — YOUNG'S MODULUS OF ELASTICITY. (Everett.)

	Dynes	Grams
Brass Wire	1.075 × $\overline{10}^{12}$	1.095 × $\overline{10}^{9}$
Copper Wire	1.234 × $\overline{10}^{12}$	1.257 × $\overline{10}^{9}$
Iron, Wrought	1.963 × $\overline{10}^{12}$	2.001 × $\overline{10}^{9}$
Steel	2.139 × $\overline{10}^{12}$	2.180 × $\overline{10}^{9}$

These results are only approximations.

TABLE XII. — ACCELERATION DUE TO GRAVITY, g, AND LENGTH, l, OF THE SECONDS PENDULUM IN LATITUDE, ϕ.

ϕ	0°	10°	20°	30°	40°	45°	50°	60°	70°	80°	90°
g	978.1	978.2	978.7	979.3	980.2	980.62	981.1	981.9	982.6	983.0	983.2
l (cm.)	99.10	99.12	99.15	99.23	99.31	99.36	99.40	99.49	99.56	99.60	99.62

TABLE XIII. — MEAN HEIGHT b OF BAROMETER AT ELEVATION H ABOVE THE SEA-LEVEL. (Kohlrausch.)

Temperature of Air at 10° C.

H Meters	H Feet	b mm.	b Inches	H Meters	H Feet	b mm.	b Inches
0	0	760	29.92	1000	3280	674	26.53
100	328	751	29.57	1100	3608	666	26.22
200	656	742	29.21	1200	3936	658	25.90
300	984	733	28.85	1300	4265	650	25.59
400	1312	724	28.50	1400	4592	642	25.27
500	1640	716	28.19	1500	4920	635	25.00
600	1968	707	27.83	1600	5248	627	24.68
700	2296	699	27.52	1700	5577	620	24.41
800	2624	690	27.17	1800	5905	612	24.09
900	2952	682	26.85	1900	6233	605	23.82
1000	3280	674	26.53	2000	6561	598	23.54

TABLE XIV. — REDUCTION OF THE BAROMETER READING TO 0° C. ON ACCOUNT OF THE EXPANSION OF THE MERCURY AND OF THE SCALE. (Kohlrausch.)

If *t* is the temperature at the time the height *h* of the mercury is taken, and β the coefficient of expansion of the metal of the scale, an amount equal to $(0.000181 - \beta)\,ht$ must be subtracted from *h* in order to obtain the reading reduced to 0°. The following results are thus obtained:

t	OBSERVED HEIGHT (*h*) IN MM.									
	680 mm.	690 mm.	700 mm.	710 mm.	720 mm.	730 mm.	740 mm.	750 mm.	760 mm.	770 mm.
1	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.12
2	0.22	0.22	0.23	0.23	0.23	0.24	0.24	0.24	0.25	0.25
3	0.33	0.34	0.34	0.35	0.35	0.35	0.36	0.36	0.37	0.37
4	0.44	0.45	0.45	0.46	0.47	0.47	0.48	0.49	0.49	0.50
5	0.55	0.56	0.57	0.58	0.58	0.59	0.60	0.61	0.62	0.62
6	0.66	0.67	0.68	0.69	0.70	0.71	0.72	0.73	0.74	0.75
7	0.77	0.78	0.79	0.81	0.82	0.83	0.84	0.85	0.86	0.87
8	0.88	0.89	0.91	0.92	0.93	0.95	0.96	0.97	0.98	0.99
9	0.99	1.01	1.02	1.04	1.05	1.06	1.08	1.09	1.11	1.12
10	1.10	1.12	1.13	1.15	1.17	1.18	1.20	1.22	1.23	1.25
11	1.21	1.23	1.25	1.27	1.28	1.30	1.32	1.34	1.35	1.37
12	1.32	1.34	1.36	1.38	1.40	1.42	1.44	1.46	1.48	1.50
13	1.43	1.45	1.47	1.50	1.52	1.54	1.56	1.58	1.60	1.62
14	1.54	1.56	1.59	1.61	1.63	1.66	1.68	1.70	1.72	1.75
15	1.65	1.68	1.70	1.73	1.75	1.77	1.80	1.82	1.85	1.87
16	1.76	1.79	1.81	1.84	1.87	1.89	1.92	1.94	1.97	2.00
17	1.87	1.90	1.93	1.96	1.98	2.01	2.04	2.07	2.09	2.12
18	1.98	2.01	2.04	2.07	2.10	2.13	2.16	2.19	2.22	2.25
19	2.09	2.12	2.15	2.19	2.22	2.25	2.28	2.31	2.34	2.37
20	2.20	2.24	2.27	2.30	2.33	2.37	2.40	2.43	2.46	2.49
21	2.31	2.35	2.38	2.42	2.45	2.48	2.52	2.55	2.59	2.62
22	2.42	2.46	2.49	2.53	2.57	2.60	2.64	2.67	2.71	2.74
23	2.53	2.57	2.61	2.65	2.68	2.72	2.76	2.79	2.83	2.87
24	2.64	2.68	2.72	2.76	2.80	2.84	2.88	2.92	2.95	2.99
25	2.75	2.79	2.84	2.88	2.92	2.96	3.00	3.04	3.08	3.12
26	2.86	2.91	2.95	2.99	3.03	3.07	3.12	3.16	3.20	3.24
27	2.97	3.02	3.06	3.11	3.15	3.19	3.24	3.28	3.32	3.37
28	3.08	3.13	3.18	3.22	3.27	3.31	3.36	3.40	3.45	3.49
29	3.19	3.24	3.29	3.34	3.38	3.43	3.48	3.52	3.57	3.62
30	3.30	3.35	3.40	3.45	3.50	3.55	3.60	3.65	3.69	3.74

TABLE XV. — DENSITY (OR SPECIFIC GRAVITY) OF SOME SOLIDS.

The five following tables give the weight, in grams per cc., of the body. These numbers should be considered only as approximations, as the density varies with the temperature and with the specimen.

SOLIDS.

Agate	2.615
Alum	1.724
Aluminum	2.670
Amber	1.078
Antimony, cast	6.720
Arsenic	5.700
Asphalt	2.500
Beeswax	0.964
Bismuth	9.800
Bone	1.900
Brass, cast	8.3+
Brass, sheet	8.440
Brick	1.6 to 2.000
Bronze	8.700
Butter	0.942
Calcium chloride	2.230
Canada Balsam	1.070
Camphor	0.988
Carbon, gas	1.800
Cedar, American	0.554
Chalk	1.8 to 2.800
Cherry	0.710
Chestnut	0.606
Coal, anthracite	1.26 to 1.800
Coal, bituminous	1.27 to 1.423
Cobalt	8.800
Cork	0.240
Copper, cast	8.830
Copper, sheet	8.900
Diamond	3.530
Ebony	1.187
Elm	0.579
Emery	3.900
Feldspar	2.600
Galena	7.580
German silver	8.620
Glass, green	2.640
Glass, crown	2.520
Glass, flint	3.0 to 3.600
Gold, 18-carat	14.880
Gold, pure	19.300
Gypsum, crystal	2.310
Granite	2.650
Graphite	2.500
Gunpowder	2.030
Guttapercha	0.970
Human body	1.070
Ice	0.918
Iceland spar	2.700
Iron, cast	7.100 to 7.600
Iron, wrought	7.800
Iron, steel	7.790
Ivory	1.920
Lead	11.350
Lignum vitæ	1.333
Limestone	3.180
Magnesium	1.750
Mahogany	0.560 to 0.852
Maple	0.755
Marble	2.720

TABLE XV. — *Continued.*

SOLIDS.

Nickel	8.570
Oak, red	0.850
Oak, white	0.779
Oak, live, dry	1.068
Paraffine	0.824 to 0.940
Phosphorus	1.830
Pine, white, dry	0.554
Pine, yellow, dry	0.461
Platinum	21.500
Poplar	0.389
Porcelain, china	2.380
Potassium	0.865
Quartz	2.650
Rock salt	2.257
Sand, quartz	2.750
Silver, 0.925 fine	10.380
Silver, pure	10.570
Slate	2.880
Sodium	0.970
Steel	7.790
Sugar, cane	1.593
Sulphur	2.033
Tallow	0.940
Tar	1.015
Tin, cast	7.290
Walnut	0.680
White metal, Babbitt	7.310
Willow	0.585
Zinc, cast	6.860
Zinc, rolled	7.200

TABLE XVI. — DENSITY OF SOME LIQUIDS.

Acetic acid	at 15° C.	1.053
Alcohol, absolute	“ “	0.7937
Alcohol, amyl	“ “	0.809
Benzine	“ “	0.890
Carbon bisulphide	“ “	1.270
Chloroform	“ “	1.499
Ether	“ “	0.720
Glycerine	“ “	1.260
Hydrochloric acid	“ “	1.220
Kerosene		0.778–0.804
Mercury	at 0° C.	13.596
Milk (cow's)	“ “	1.030
Molasses		1.426
Naphtha		0.748
Nitric acid	at 15° C.	1.520
Oil, castor	“ “	0.970
Oil, linseed, boiled		0.940
Oil, olive,	at 15° C.	0.915
Oil, turpentine	“ “	0.872
Petroleum		0.836
Sulphuric acid		1.840
Vinegar		1.026
Water, sea,	at 0° C.	1.026
Water	“ “	0.999
Water	at 4.07° C.	1.000
Water	at 100° C.	0.958

TABLE XVII. — DENSITY OF SOME GASES.

	At 0°C. Temperature and 760 mm. Pressure Compared with Water	Compared with Air at Similar Pressure and Temperature	Compared with Hydrogen
Air	0.0012931	1.00000	14.445
Ammonia	0.0007594	0.53670	7.7526
Aqueous vapor	0.0008040	0.62180	8.982
Carbon dioxide	0.0019650	1.520	21.950
Chlorine	0.0044482	3.4400	49.8118
Hydrogen	0.00008952	0.06923	1.000
Mixed gases from electrolysis of water	0.0005360	0.41450	5.987
Nitrogen	0.0012544	0.9701	14.013
Oxygen	0.0014291	1.1052	15.964

TABLE XVIII. — SPECIFIC GRAVITY OF AQUEOUS SOLUTIONS AT 15° C. REFERRED TO WATER AT 4°. (Mostly from Kohlrausch and Gerlach.) Percentages 0 to 50.

The percentages indicate the weight of the substance contained in 100 parts by weight of the solution. The salts are anhydrous.

%	KHO	KI	KNO_3	$K_2Cr_2O_7$	NH_3	NH_4Cl	NaHO	NaCl	%
0	0.999	0.999	0.999	0.999	0.999	0.9991	0.999	0.999	0
5	1.045	1.037	1.031	1.036	0.978	1.0149	1.056	1.035	5
10	1.092	1.077	1.064	1.072	0.958	1.0299	1.111	1.072	10
15	1.141	1.119	1.099	1.109	0.941	1.0443	1.166	1.110	15
20	1.191	1.165	1.135		0.924	1.0584	1.222	1.150	20
25	1.242	1.217			0.910	1.0721	1.277	1.191	25
30	1.295	1.270			0.897		1.333		30
35	1.349	1.330			0.885		1.387		35
40	1.406	1.395					1.442		40
45	1.466	1.468					1.496		45
50	1.528	1.545					1.548		50

TABLE XIX. — SPECIFIC GRAVITY OF AQUEOUS SOLUTIONS AT 15° C. REFERRED TO WATER AT 4°. (Mostly from Kohlrausch and Gerlach.) Percentages 0 to 100.

%	$CaCl_2$	$ZnSO_4$	$CuSO_4$	HCl	HNO_3	H_2SO_4	Alcohol	Sugar at 17.5°	%
0	0.999	0.999	0.999	0.9991	0.999	0.9991	0.9991	0.9987	0
5	1.042	1.052	1.050	1.0242	1.029	1.0334	0.9904	1.0184	5
10	1.086	1.108	1.103	1.0490	1.058	1.0687	0.9831	1.0388	10
15	1.133	1.168	1.161	1.0744	1.089	1.1048	0.9769	1.0600	15
20	1.181	1.236	1.225	1.1001	1.121	1.1430	0.9708	1.0819	20
25	1.232	1.307		1.1262	1.154	1.1816	0.9644	1.1047	25
30	1.286	1.382		1.1524	1.187	1.223	0.9569	1.1282	30
35	1.343			1.1775	1.220	1.264	0.9485	1.1526	35
40	1.402			1.2007	1.253	1.307	0.9390	1.1780	40
45					1.287	1.352	0.9287	1.2041	45
50					1.320	1.399	0.9179	1.2313	50
55					1.350	1.449	0.9068	1.2593	55
60					1.377	1.503	0.8954	1.2883	60
65					1.402	1.559	0.8838	1.3183	65
70					1.424	1.616	0.8720	1.3494	70
75					1.443	1.675	0.8601	1.3813	75
80					1.461	1.733	0.8479		80
85					1.479	1.785	0.8354		85
90					1.497	1.819	0.8224		90
95					1.514	1.839	0.8086		95
100					1.530	1.8384	0.7937		100

TABLE XX. — CONDUCTING POWER FOR HEAT OF SOME SUBSTANCES. (Approximations.)

Bismuth	1.8	Palladium	6.3
Brass	23.6	Platinum	9.2
Copper	73.6	Silver	100.0
German silver	8.0	Steel	11.6
Glass	0.1	Tin	14.5
Iron	16.5	Zinc	26.0
Lead	8.5		

The above table is taken mainly from the work of MM. Wiedemann and Franz and gives the conducting power of these substances as compared with silver.

TABLE XXI. — BOILING TEMPERATURE t OF WATER AT BAROMETRIC PRESSURE b. (From Regnault's observations.)

b	t	b	t	b	t	b	t	b	t
680	96.92°	700	97.72°	720	98.49°	740	99.26°	760	100.00°
681	.96	01	.75	21	.53	41	.29	61	.04
682	97.00	02	.79	22	.57	42	.33	62	.07
683	.04	03	.83	23	.61	43	.37	63	.11
684	.08	04	.87	24	.65	44	.41	64	.15
685	.12	05	.91	25	.69	45	.44	65	.18
686	.16	06	.95	26	.72	46	.48	66	.22
687	.20	07	97.99	27	.76	47	.52	67	.26
688	.24	08	98.03	28	.80	48	.56	68	.29
689	.28	09	.07	29	.84	49	.59	69	.33
690	.32	710	.11	730	.88	750	.63	770	.36
691	.36	11	.15	31	.92	51	.67	71	.40
692	.40	12	.19	32	.95	52	.70	72	.44
693	.44	13	.22	33	98.99	53	.74	73	.47
694	.48	14	.26	34	99.03	54	.78	74	.51
695	.52	15	.30	35	.07	55	.82	75	.55
696	.56	16	.34	36	.11	56	.85	76	.58
697	.60	17	.38	37	.14	57	.89	77	.62
698	.64	18	.42	38	.18	58	.93	78	.65
699	.68	19	.46	39	.22	59	.96	79	.69
700	97.72	720	98.49	740	99.26	760	100.00	80	100.72

Table XXII. — Melting Points and Heats of Liquefaction (Latent Heats) of Some Substances. (Everett and Violle.)

	Melting Point	Latent Heat of Liquefaction		Melting Point	Latent Heat of Liquefaction
Aluminum . .	606° C.		Mercury . .	−40° C.	2.82
Antimony . .	432		Nickel . . .	1450	4.64
Bismuth. . .	260	12.6	Palladium. .	1500	36.3
Bromine. . .	−7		Paraffine . .	54	
Cadmium . .	315	13.6	Phosphorus .	44	5.0
Copper . . .	1054		Platinum . .	1775	27.2
Glass. . . .	1100		Selenium . .	217	
Ice	0	80	Silver . . .	954	24.7
Iodine . . .		11.7	Sodium . .	96	
Iridium . . .	1950		Sulphur . .	115	9.4
Iron	1600		Tin	230	14.6
Lead. . . .	326	5.4	Zinc . . .	412	28.1

Table XXIII. — Boiling Points and Heats of Vaporization (Latent Heats) of Some Substances.

	Boiling Point	Latent Heat of Vaporization	Observer
Alcohol	77.9° C.	202.4	Andrews
Bisulphide of Carbon . . .	46.2	86.7	Andrews
Bromine.	58.0	45.6	Andrews
Ether	34.9	90.4	Andrews
Mercury.	350.0	62.0	Person
Turpentine	159.3	74.0	Brix
Water	100.	535.9	Andrews

TABLE XXIV. — FOR HYGROMETRY.

Pressure of aqueous vapor (p), in mm. of mercury, and weight of water (w), in grams, contained in 1 cubic meter of air at the dew point (t) C.°.

t C.°	p mm.	w g.	t C.°	p mm.	w g.	t C.°	p mm.	w g.	t C.°	p mm.	w g.
−10°	2.0	2.1	0°	4.6	4.9	10°	9.1	9.4	20°	17.4	17.2
− 9	2.2	2.4	1	4.9	5.2	11	9.8	10.0	21	18.5	18.2
− 8	2.4	2.7	2	5.3	5.6	12	10.4	10.6	22	19.7	19.3
− 7	2.6	3.0	3	5.7	6.0	13	11.1	11.3	23	20.9	20.4
− 6	2.8	3.2	4	6.1	6.4	14	11.9	12.0	24	22.2	21.5
− 5	3.1	3.5	5	6.5	6.8	15	12.7	12.8	25	23.6	22.9
− 4	3.3	3.8	6	7.0	7.3	16	13.5	13.6	26	25.0	24.2
− 3	3.6	4.1	7	7.5	7.7	17	14.4	14.5	27	26.5	25.6
− 2	3.9	4.4	8	8.0	8.1	18	15.4	15.1	28	28.1	27.0
− 1	4.2	4.6	9	8.5	8.8	19	16.3	16.2	29	29.8	28.6
0	4.6	4.9	10	9.1	9.4	20	17.4	17.2	30	31.6	30.1

TABLE XXV.—DENSITY Q OF WATER AT TEMPERATURE t° C.°.

(From determinations of Halturön, Jolly, Kopp, Matthiessen, and Pierre.)

t C.°	Q	Difference	t C.°	Q	Difference
0°	0.99988	− 5	15	0.99915	15
1	0.99993	− 4	16	0.99900	15
2	0.99997	− 2	17	0.99884	16
3	0.99999	− 1	18	0.99866	18
4	1.00000	+ 1	19	0.99847	19
5	0.99999	2	20	0.99827	20
6	0.99997	3	21	0.99806	21
7	0.99994	6	22	0.99785	21
8	0.99988	6	23	0.99762	23
9	0.99982	8	24	0.99738	24
10	0.99974	9	25	0.99714	24
11	0.99965	10	26	0.99689	25
12	0.99955	12	27	0.99662	27
13	0.99943	13	28	0.99635	27
14	0.99930	15	29	0.99607	28
15	0.99915	15	30	0.99579	28

Density of water at 100°, 0.95865.
" " ice " 0°, 0.918.

TABLE XXIX. — COEFFICIENTS OF LINEAR EXPANSION FOR 1° C. (Kohlrausch.)

Aluminum	0.000023	Lead	0.000029
Brass	0.000019	Platinum	0.000009
Copper	0.000017	Silver	0.000019
German silver	0.000018	Tin	0.000023
Glass	0.0000085	Wood with the grain	0.000003–10
Gold	0.000015	Zinc	0.000029
Iron	0.000012		

TABLE XXX. — COEFFICIENTS OF CUBICAL EXPANSION OF SOME SOLIDS. (Everett.)

Brass	0.000053–56	Platinum	0.000026–29
Copper	0.000052–57	Silver	0.000057–64
Glass	0.000023–28	Steel	0.000032–42
Iron	0.000035–44	Tin	0.000058–69
Lead	0.000084–89	Zinc	0.000087–90

TABLE XXXI. — COEFFICIENTS OF CUBICAL EXPANSION OF SOME LIQUIDS. (*Centigrade.*)

Alcohol, ethyl, 0°–50°	0.001080	Glycerine at 0°	0.000526
Benzine, 11°–81°	0.001385	Mercury, 0°–100°	0.000181
Carbon bisulphide	0.001468	Olive oil, 0°–100°	0.00080
Chloroform	0.001400	Turpentine	0.001050
Ether, 0°–33°	0.0021		
Water	0.00012 at 15° C. to 0.00074 at 90° C.		

Gases expand 0.003665 ($\frac{1}{273}$) of their volume at 0° for each degree Centigrade; in other words, the amount of their expansion for 1° C. is the reciprocal of their absolute temperature.

TABLE XXXII. — SPECIFIC HEAT OF SOME BODIES, REFERRED TO WATER.

SOLIDS.

Aluminum	0.2135	Ice	0.5040
Antimony	0.0507	Iron	0.1125
Bismuth	0.0305	Lead	0.0317
Brass	0.0940	Nickel	0.1100
Copper	0.0933	Platinum	0.0320
German silver	0.0946	Quartz	0.1910
Glass	0.1900	Silver	0.0559
Gold	0.0320	Tin	0.0559
Zinc	0.0935		

LIQUIDS.

Alcohol at 17° C.	0.580	Glycerine, 0°–100° C.	0.555
Carbon disulphide at 15° C.	0.230	Mercury at 15° C.	0.033
Chloroform " "	0.233	Turpentine at 17° C.	0.430
Ether " "	0.530	Water	1.000

GASES AT CONSTANT PRESSURE (by weight).

Air	0.2375	Oxygen	0.2175
Hydrogen	3.4090	Steam	0.4805
Nitrogen	0.2438		

TABLE XXXIII. — HEATS OF COMBUSTION. (Favre and Silbermann.)

Alcohol	7184	Hydrogen (with chlorine)	23783
Carbon dioxide	3403	Marsh-gas	13063
Carbon disulphide	3400	Native sulphur	2261
Charcoal	8080	Oil of turpentine	10852
Diamond	7770	Olefiant gas	11857
Ether	9028	Olive oil	9862
Graphite	7797	Soft sulphur	2258
Hydrogen	34462	Stearic acid	9616

TABLE XXXIV.—APPROXIMATE E. M. F. OF SOME PRIMARY CELLS. (Carhart.)

Bichromate of potassium or sodium	2.00	volts.
Bunsen	1.90	"
Carhart-Clark standard cell at 15° C.	1.44	"
Chloride of silver	1.10	"
Daniell	1.08	"
Edison-Lalande	0.70	"
Gravity	1.80	"
Grove	1.90	"
Leclanché	1.4 to 1.70	"
Partz acid gravity	2.00	"

EXPLANATION OF TABLE XXXV. — It is evident that the sine of 1° is 0.017, and so on down the column to the bottom, the sine of 45° being 0.707. Now find the column named sine, at the bottom, and proceed *up* this column from 45° to 90°, the sine of 75° being 0.966. This explanation applies equally to the tangent and the other functions. "Difference" in the table means difference between the number just above and the one just below, at the left.

TABLE XXXV. — TRIGONOMETRICAL FUNCTIONS.

(For explanation, see p. 308.)

Angle	Sine	Difference	Tangent	Difference	Cotangent	Difference	Cosine	Difference	
0°	0.000	17	0.000	17	∞		1.000	0	90°
1	0.017	18	0.017	18	57.29		1.000	0	89
2	0.035	17	0.035	17	28.64		0.999	0	88
3	0.052	18	0.052	18	19.08		0.999	1	87
4	0.070	17	0.070	17	14.30		0.998	2	86
5	0.087	18	0.087	18	11.43		0.996	1	85
6	0.105	17	0.105	18	9.514		0.995	2	84
7	0.122	17	0.123	18	8.144		0.993	3	83
8	0.139	17	0.141	17	7.115	811	0.990	2	82
9	0.156	18	0.158	18	6.314	643	0.988	3	81
10°	0.174	17	0.176	18	5.671	526	0.985	3	80°
11	0.191	17	0.194	19	5.145	440	0.982	4	79
12	0.208	17	0.213	18	4.705	374	0.978	4	78
13	0.225	17	0.231	18	4.331	320	0.974	4	77
14	0.242	17	0.249	16	4.011	279	0.970	4	76
15	0.259	17	0.268	19	3.732	245	0.966	5	75
16	0.276	16	0.287	19	3.487	216	0.961	5	74
17	0.292	17	0.306	19	3.271	193	0.956	5	73
18	0.309	17	0.325	19	3.078	174	0.951	5	72
19	0.326	16	0.344	20	2.904	157	0.946	6	71
20°	0.342	16	0.364	20	2.747	142	0.940	6	70°
21	0.358	17	0.384	20	2.605	130	0.934	7	69
22	0.375	16	0.404	20	2.475	119	0.927	6	68
23	0.391	16	0.424	21	2.356	110	0.921	7	67
24	0.407	16	0.445	21	2.246	101	0.914	8	66
25	0.423	15	0.466	22	2.145	95	0.906	7	65
26	0.438	16	0.488	22	2.050	87	0.899	8	64
27	0.454	15	0.510	22	1.963	82	0.891	8	63
28	0.469	16	0.532	22	1.881	77	0.883	8	62
29	0.485	15	0.554	23	1.804	73	0.875	9	61
30°	0.500	15	0.577	24	1.732	67	0.866	9	60°
31	0.515	15	0.601	24	1.664	64	0.857	9	59
32	0.530	15	0.625	24	1.600	60	0.848	9	58
33	0.545	14	0.649	26	1.540	57	0.839	10	57
34	0.559	15	0.675	25	1.483	55	0.829	10	56
35	0.574	14	0.700	27	1.428	52	0.819	10	55
36	0.588	14	0.727	27	1.376	49	0.809	10	54
37	0.602	14	0.754	27	1.327	47	0.799	11	53
38	0.616	13	0.781	29	1.280	45	0.788	11	52
39	0.629	14	0.810	29	1.235	43	0.777	11	51
40°	0.643	13	0.839	30	1.192	42	0.766	11	50°
41	0.656	13	0.869	31	1.150	39	0.755	12	49
42	0.669	13	0.900	33	1.111	39	0.743	12	48
43	0.682	13	0.933	32	1.072	36	0.731	12	47
44	0.695	12	0.966	35	1.036	36	0.719	12	46
45°	0.707		1.000		1.000		0.707		45°
	Cosine		Cotangent		Tangent		Sine		Angle

TABLE XXXVI. — DIMENSIONS AND FUNCTIONS OF COPPER WIRES.

For sizes of music wire, see Table XL. The dimensions of other wire are the same as those of copper.

GAUGE NUMBER	DIAMETER		CIRCULAR MILS.	SECTIONAL AREA IN SQUARE INCHES	SECTIONAL AREA IN SQUARE MM.	WEIGHT AND LENGTH (DENSITY = 8.9.)		RESISTANCE AT 24° C.			CAPACITY IN AMPERES
	Mils.	Milli-meters				Lbs. per 1000 Ft.	Feet per Lb.	Ohms per 1000 Ft.	Feet per Ohm	Ohms per Lb.	
0000	460.000	11.684	211600.00	0.166190	107.219	639.33	1.56	0.051	19929.700	0.0000785	312.
000	409.640	10.405	167805.00	0.131790	85.028	507.01	1.97	0.063	15804.900	0.000125	262.
00	364.800	9.266	133079.40	0.104520	67.431	402.09	2.49	0.080	12534.200	0.000198	220.
0	324.950	8.254	105592.50	0.082932	53.470	319.04	3.13	0.101	9945.300	0.000315	185.
1	289.300	7.348	83694.20	0.065733	42.409	252.88	3.95	0.127	7882.800	0.000501	156.
2	257.630	6.544	66373.00	0.052130	33.631	200.54	4.99	0.160	6251.400	0.000799	131.
3	229.420	5.827	52634.00	0.041339	26.670	159.03	6.29	0.202	4957.300	0.001268	110.
4	204.310	5.189	41742.00	0.032784	21.151	126.12	7.93	0.254	3931.600	0.002016	92.3
5	181.940	4.621	33102.00	0.025998	16.773	100.01	10.00	0.321	3117.800	0.003206	77.6
6	162.020	4.115	26250.50	0.020617	13.301	79.32	12.61	0.404	2472.400	0.005098	65.2
7	144.280	3.665	20816.00	0.016349	10.548	62.90	15.90	0.509	1960.600	0.008106	54.8
8	128.490	3.264	16509.00	0.012966	8.366	49.88	20.05	0.643	1555.000	0.01289	46.1
9	114.430	2.907	13094.00	0.010284	6.655	39.56	25.28	0.811	1233.300	0.02048	38.7
10	101.890	2.588	10381.00	0.0081532	5.260	31.37	31.38	1.023	977.800	0.03259	32.5
11	90.742	2.305	8234.00	0.0064670	4.172	24.88	40.20	1.289	775.500	0.05181	27.3
12	80.808	2.053	6529.90	0.0051286	3.309	19.73	50.69	1.626	615.020	0.08237	23.0
13	71.961	1.828	5178.40	0.0040671	2.618	15.65	63.91	2.048	488.250	0.13087	19.3
14	64.084	1.628	4106.80	0.0031469	2.081	12.41	80.59	2.585	386.800	0.20830	16.2
15	57.068	1.450	3256.70	0.0025578	1.650	9.84	101.63	3.177	306.740	0.33133	13.6
16	50.820	1.291	2582.90	0.0020286	1.309	7.81	128.14	4.582	243.250	0.52638	11.5
17	45.257	1.150	2048.20	0.0016086	1.038	6.19	161.59	5.183	192.910	0.83744	9.6
18	40.303	1.024	1624.30	0.0012757	0.823	4.91	203.76	6.536	152.990	1.3312	8.1

19	35.390	0.899	1252.40	0.0009836	0.6527	3.78	264.26	8.477	117.960	2.2392	6.7
20	31.961	0.812	1021.50	0.0008023	0.5176	3.09	324.00	10.394	96.210	3.3438	5.7
21	28.462	0.723	810.10	0.0006363	0.4105	2.45	408.56	13.106	76.300	5.3539	4.8
22	25.347	0.644	642.70	0.0005048	0.3255	1.94	515.15	16.525	60.510	8.5099	4.0
23	22.571	0.573	509.45	0.0004001	0.2581	1.54	649.66	20.842	47.980	13.334	3.2
24	20.100	0.511	504.01	0.0003173	0.2047	1.22	819.21	26.284	38.050	21.524	2.8
25	17.900	0.455	320.40	0.0002516	0.1624	0.97	1032.96	33.135	30.180	34.298	2.4
26	15.940	0.405	254.01	0.0001995	0.1288	0.77	1302.61	41.789	23.930	54.410	2.0
27	14.195	0.361	201.50	0.0001583	0.1021	0.61	1642.55	52.687	18.980	86.657	1.7
28	12.641	0.321	159.79	0.0001255	0.08097	0.48	2071.22	66.445	15.050	137.283	1.4
29	11.257	0.286	126.72	0.0000995	0.06421	0.38	2611.82	83.752	11.940	218.104	1.2
30	10.025	0.255	100.50	0.0000789	0.05092	0.30	3293.97	105.641	9.466	349.805	1.0
31	8.928	0.227	79.71	0.0000626	0.04039	0.24	4152.22	133.191	7.508	557.286	0.84
32	7.950	0.202	63.20	0.0000496	0.03203	0.19	5236.66	168.011	5.952	884.267	0.70
33	7.080	0.180	50.13	0.0000394	0.02539	0.15	6602.71	211.820	4.721	1402.78	0.60
34	6.304	0.160	39.74	0.0000312	0.02014	0.12	8328.30	267.165	3.743	2207.98	0.50
35	5.614	0.143	31.57	0.0000248	0.01597	0.10	10501.35	336.810	2.969	3583.12	0.42
36	5.000	0.127	25.00	0.0000196	0.01267	0.08	13238.83	424.650	2.355	5661.71	0.35
37	4.453	0.113	19.83	0.0000156	0.01005	0.06	16691.06	535.330	1.868	8922.20	0.27
38	3.965	0.101	15.72	0.0000123	0.00797	0.05	20854.65	675.220	1.481	15000.50	0.25
39	3.531	0.090	12.47	0.0000098	0.00632	0.04	26302.23	821.789	1.174	22415.50	0.21
40	3.144	0.080	9.89	0.0000078	0.00501	0.03	33175.94	1074.110	0.931	35803.80	0.17

TABLE XXXVII. — RELATIVE AND SPECIFIC RESISTANCES.

The specific resistance of a substance is the resistance between opposite faces of a cube of that substance, one centimeter on each edge. In the English system a cube one inch on each edge is considered.

$$R = \frac{\text{Sp R} \times \text{length}}{\text{area}}, \text{ or } R = \frac{\text{Sp R} \times 1.2737 \times l}{d^2}.$$

This latter expression is derived from the first.

Chemically pure substances arranged in order of increasing resistance, from 20° C., for the same length and sectional area. (Ayrton.)

	Sp. R. in Microhms at 0° C.		Relative Resistance	% of Increase for 1° C. (from 20° C.)
	c.c.	cu. in.		
Silver, annealed	1.504	0.5921	1.000	0.377
Copper, "	1.598	0.6292	1.063	0.388
Silver, hard drawn	1.634	0.6433	1.086	
Copper, " "	1.634	0.6433	1.086	
Aluminum, annealed	2.912	1.147	1.935	
Platinum, "	9.057	3.565	6.022	
Iron, "	9.716	3.825	6.460	0.50 about
Nickel, "	12.470	4.907	8.285	
German silver	20.930	8.240	13.92	0.044
Platinoid	34.000		22.61	0.021
Mercury	94.320	37.15	37.15	0.072

TABLE XXXVIII. — ABSORPTION OF ELECTRIC LIGHT BY GLOBES. (Geipel & Kilgour and von Hefner-Alteneck.)

See Sloane's "Dictionary of Electricity."

Kind of Glass.	Per cent absorbed.
Alabaster	15 to 25
Clear	10 " 20
Ground	30 " 40
Heavily ground	40 " 50
Heavy opal	50 " 60
Opal	15 " 25

Large globes absorb more light than small ones.

TABLE XXXIX. — VELOCITY OF SOUND IN SOME BODIES.

			Meters.
Air	at 0° C.	per sec.	332
Brass	at 17° C.	"	3200
Copper	"	"	3700
Glass	"	"	5000
Iron	"	"	5000
Lead	"	"	1300
Maple		"	4100
Oak		"	3800
Pine		"	3300
Steel	at 17° C.	"	5100
Water	at 8.1° C.	"	1435

TABLE XL. — SIZES AND NUMBERS OF STEEL, MUSIC, OR PIANO WIRE. (English.)

(For other wire, see Table XXXVI.)

Gauge No.	Diameter in Inches	Gauge No.	Diameter in Inches
1	0.0087	16	0.0360
2	0.0105	17	0.0380
3	0.0115	18	0.0400
4	0.0125	19	0.0420
5	0.0145	20	0.0430
6	0.0150	21	0.0445
7	0.0175	22	0.0470
8	0.0190	23	0.0490
9	0.0220	24	0.0530
10	0.0245	25	0.0560
11	0.0270	26	0.0605
12	0.0285	27	0.0640
13	0.0305	28	0.0685
14	0.0320	29	0.0715
15	0.0350	30	0.0750

Table XLI. — Pitch and Number of Vibrations per Second of Musical Tones.

	C_{-2}	C_{-1}	C	c	c_1	c_2	c_3	c_4
C	16.35	32.70	65.41	130.8	261.7	523.3	1047	2093
C♯	17.32	34.65	69.30	138.6	277.2	554.4	1109	2218
D	18.35	36.71	73.42	146.8	293.7	587.4	1175	2350
D♯	19.44	38.89	77.79	155.6	311.2	622.3	1245	2489
E	20.60	41.20	82.41	164.8	329.7	659.3	1319	2637
F	21.82	43.65	87.31	174.6	349.2	698.5	1397	2794
F♯	23.12	46.25	92.50	185.0	370.0	740.0	1480	2960
G	24.50	49.00	98.00	196.0	392.0	784.0	1568	3136
G♯	25.95	51.91	103.8	207.6	415.3	830.6	1661	3322
A	27.50	55.00	110.0	220.0	440.0	880.0	1760	3520
A♯	29.13	58.27	116.5	233.1	466.2	932.3	1865	3729
B	30.86	61.73	123.5	246.9	493.9	988.7	1975	3951

Table XLII. — Mean Index of Refraction, and Dispersion of Some Bodies.

Vaccuum to	Index of Refraction	Dispersion
Air	1.000294	
Alcohol	1.372	0.0133
Canada balsam	1.54	
Carbon disulphide	1.68	
Diamond	2.47	0.0837
Ether	1.36	
Glass, crown	1.53	0.022
Glass, flint	1.60	0.042
Ice	1.31	
Lead chromate	2.5–2.97	
Rock salt	1.54	
Sea water	1.34	
Turpentine	1.48	
Water	1.336	0.0132

APPENDIX III.

LIST OF APPARATUS AND SUPPLIES.

For the convenience of teachers the following list of apparatus and supplies required for this course is here given. The number of the experiment in which each piece of apparatus is used is also given.

A. Apparatus.

Measuring and Properties of Matter.

		EXP. NO.
1	Apparatus, indicating, for elasticity of flexure	13
1	Apparatus, torsion of rods	16
1	Balance, Chatillon spring, "yarn tester"	17
1	Balance, Jolly	15
1	Balance, sensitive	5, 6
1	Balance, specific gravity	11
1	Balance, spring, 15 kg.	14
1	Barometer of Exp. 32	2
1	Brass tube about 2 cm. diameter	1, 2
1	Burette 50 cc. × 0.1 cc., and holder	6
1	Caliper, exterior-interior, 4″ Sterrett	1
1	Caliper, micrometer B. & S. metric	3, 14, 17
1	Caliper, vernier, metric	2
1	Capillary tubes, set of 4	12
1	Glass plate for cohesion	11
1	Graduate, metric	1
2	Handscrews, wooden, No. 10	14
1	Lens of Exp. 130	4
1	Oxygen generator	7
1	Piece ignition glass tubing 20 cm. × 2 cm.	7
1	Piece plate glass	4

		EXP. NO.
1	Rod, maple, 102 × 1 × 1 cm.	13
1	Rod, pine, 102 × 1 × 1 cm.	13
1	Rod, pine, 102 × 2 × 1 cm.	13
1	Rod for torsion experiment	16
1	Scale, metric and English, 10 cm.	1
1	Sphere, brass or iron	1, 2
1	Spherometer	4
1	Test-tube, 5 inch	9
1	Thistle tube	8
1	Weights, set of metric, 1 cg.–1 kg.	6
1	Wooden cylinder 10 × 2 cm.	17

Mechanics.

1	Air pump	31
1	Apparatus for Boyle's law	35
1	Apparatus for falling bodies	19
3	Balances, spring, 1500 g.	21, 22, 27, 28
1	Balance, sp. gr., of Exp. 11	27–30
1	Balance of Exp. 6	31
4	Balls for pendulums	20
1	Bar of wood 25 × 1 × 1 cm.	38
1	Barometer, U. S. Standard, English and metric scale	32
1	Block oak, 20 × 10 × 5 cm.	30
1	Block pine, 20 × 10 × 5 cm.	30
2	Boards, smooth, 100 × 20 cm., hinged together at one end	29, 30
1	Bottle, 2 liter	31
1	Caliper, vernier, of Exp. 2	25
1	Cart, small	29
1	Cylinder or sphere of brass	37
1	Hydrometer jar	38
2	Levers, wood, 30 × 2.5 × 0.5 cm.	23–25
1	Model force and lift pump	33
1	Pulley, double	28
1	Pulley, single	28
1	Seconds clock or pendulum	20
1	Set of lever weights, brass, two 5 g., two 10 g., one 20 g.	23–25
1	Suspension clamp for pendulums	20
1	Wheel and axle	27

Specific Gravity.

		EXP. NO.
1	Balance of Exp. 6	39, 44, 45
1	Balance, Jolly of Exp. 15	41, 43, 47
1	Balance, specific gravity	40, 42, 46, 51
1	Bottle, specific gravity, 25 cc. at 20° C.	40, 45
1	Hydrometer jar and hydrometer of Exp. 38	50

Heat.

1	Air pump of Exp. 31	60
1	Air thermometer bulb	53, 61
1	Apparatus for conduction of heat	54
1	Apparatus for linear expansion	64
1	Balance of Exp. 6	67–70
1	Barometer of Exp. 32	58
1	Beaker, copper, 200 cc.	57, 61, 62, 67–70
1	Calorimeter	63, 70
1	Copper boiler	58, 60, 64, 66, 68, 69
1	Sphere or cylinder of Exp. 1	69
1	Test-tube, side neck, 6″	60
1	Thermometer, chemical, scale on stem, −30° to 200° C.	52, 53, 57–60, 62–70
1	Trough, shallow	66

Electricity and Magnetism.

1	Ammeter 0–18 amperes	101
3	Blue print paper, 3 pieces	80
2	Carbons, electric light	88
1	Catskin	86
1	Commutator	91, 92, 94–97, 99, 103–105
1	Commutator, Pohl's	106
1	Compass (magnetoscope)	74–81, 89
2	Dissected dynamos	108
1	Electrophorus	86
1	Electroscope, gold leaf	85
1	Galvanometer, D'Arsonval	97, 98, 100, 102, 107
1	Galvanometer tangent	91–96, 99, 103–106, 108
2	Glass rods 30 × 1 cm.	82–85
1	Leyden jar and discharger	86

		EXP. NO.
2	Magnets, bar, 6 in.	71–80
1	Magnet, horseshoe, 6 in.	79
1	Magnet, horseshoe electro-	107
1	Piece flannel	82–85
1	Piece silk (best quality)	82–85
1	Primary and secondary coil	107
1	Resistance box	91, 92, 94–106
1	Resistance spools	91, 96
2	Rods, soft iron, 10 cm. long	74, 79, 90
2	Rods, vulcanite or sealing wax, 30 × 2 cm.	82–85
1	Sieve (pepper-box)	80
1	Slide wire bridge	98, 100, 102
2	Spring contact keys	97, 98, 100, 102
2	Spherical shells, brass	84
2	Voltaic cells, Daniell	94, 95, 103, 105
1	Voltaic cell, Edison-Lalande	104
5	Voltaic cells, bichromate	94, 107
1	Voltaic cell, Dry (Phœnix)	—
1	Voltaic cell, Globe Fuller	—
1	Voltaic cell, gravity	—
1	Voltmeter 0–18 volts	101

Sound.

1	Air pump of Exp. 31	113
1	Apparatus for Chladni's figures	112
1	Apparatus for determining number of vibrations of tuning fork	118
1	Bell, small	111
1	Cord, solid rubber, 3 m. long	110
1	Electric bell	113
1	Glass tube, 1.2 m. long × 2.5 mm. in diameter	114, 115, 121
1	Ripple trough	109
1	Sonometer	119, 120
1	Tuning fork	111, 112, 115, 116, 120
1	Tuning fork, diapason	117
1	Violin bow	112, 119, 120
1	Wave trough	109

Light.

1	Chemical projection tank for liquids	132
1	Lens, biconvex, 5 cm. focal length	130, 131

		EXP. NO.
1	Lens, biconvex, 8 cm. focal length	130, 131
1	Lens, biconvex, 40 cm. focal length	131, 132
1	Lens, biconcave, small	130, 131
1	Mirror, concave	127
1	Mirror, convex	127
1	Mirror, plane, 10 × 5 cm.	126
1	Newton's disk	132
1	Piece of plate glass 4 × 5 cm.	128, 129
1	Prism, glass	128
2	Prisms, hollow, for bisulphide of carbon	132
1	Projecting lantern, oxyhydrogen or electric	132
1	Protractor 4½″	126
1	Rotator	132
1	Set of colored glasses 10 × 12 cm.	132
1	Set of wooden or pasteboard screens	122–124

B. SUPPLIES.

Alcohol 95%.
Argand lamp chimney.
Battery jar.
Blocks of wood, two, 10 × 5 × 5 cm.
Bunsen blast lamp.
Bunsen burner.
Calcium chloride.
Candles, wax.
Carbon bisulphide.
Chapman's brass filter pump with adapter.
Clamp, iron, 3″.
Copper sulphate, crystals.
Cord, braided linen (fish line).
Corks of various sizes.
Cotton twine.
Dish, glass or porcelain.
Dividers with pencil holder.
Double connectors.
Emery paper.
Ether.
Files, triangular and round.
Flask 150 cc.
Flask 1000 cc.
Foot bellows.
Gimlet.
Glass beaker 150 cc.
Glass funnel.
Glass microscope cover.
Glass microscope slide.
Glue.
Glycerine.
Gummed labels.
Hydrochloric acid.
Ice.
Iron filings.
Iron weights, 3, 6, 12 kgs.
Kerosene.
Linseed oil, boiled.
Manganese dioxide.
Mercury.
Meter stick.
Mica.
Nails of various sizes.

Nitric acid.
Olive oil.
Paper of pins.
Paraffine.
Pinchcocks, Mohr's stiff.
Pipette with rubber bulb (pen filler).
Pith.
Potassium chlorate.
Potassium hydroxide.
Potassium iodide.
Potassium nitrate.
Retort stand with rings and clamp.
Rubber bands Nos. 9 and 10.
Rubber stoppers, one-hole, to fit 150 cc. flask.
Rubber stoppers, one-hole, No. 8, to fit top of boiler.
Rubber stoppers, solid, to fit large end of Argand lamp chimney.
Rubber stoppers, three-hole, to fit small end of Argand lamp chimney.
Rubber stoppers, two-hole, to fit 150 cc. flask.
Salt.
Sand.
Sandpaper.
Screw hooks.
Shears for cutting sheet metal.
Sheet copper, iron, lead, and zinc.
Shellac varnish.
Sodium bichromate.
Solids to be tested for specific gravity.
Strip of tinned iron.
Sugar charcoal.
Sulphuric acid.
Tacks, carpet, one paper.
Tacks, double pointed, one paper.
Tacks, small, one paper.
Tallow.
Thread, cotton, No. 24.
Thread, silk.
Touch paper for Exp. 66.
Tubes, Y or T (see Exp. 32).
Tubing, glass, assorted sizes.
Tubing, rubber, black, $\frac{3}{16}''$, $\frac{1}{4}''$.
Tubing, rubber, pressure $\frac{5}{16}''$.
Tumbler with flat bottom.
Varnish brush.
Vial, small homœopathic.
Watch springs.
Window glass.
Wire annunciator, No. 18.
Wire, copper, double covered.
Wire, German silver, No. 30.
Wire, iron, No. 28.
Wire, piano steel, No. 1.
Wire, spring brass, Nos. 22, 26, and 28.
Wire gauze 10 × 12 cm.
Wooden triangular prisms 3 or 4 cm. long and faces about 2 cm. wide.

Every physical laboratory should possess a set of tools, including hammer, monkey wrench, gas pliers, shears for cutting sheet metal, flat-nose pliers, cutting pliers, two saws, ripping and cross-cut, brace with drills and bits, sizes $\frac{1}{16}''$ to $\frac{3}{4}''$, jack plane, smoothing plane, T-square, screwdriver, two chisels, $\frac{1}{2}''$ and 1″, draw knife, a glass cutter, and a vise. There should also be a screw-cutting lathe, as with this machine very many pieces of apparatus can be constructed by the pupils under the direction of the instructor.

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0° 1089 ft per
20° 1125 ft
Increase per
0° 332
20° 343
Increase

Durand